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THE WATER REQUIREMENT OF CERTAIN CROP PLANTS AND WEEDS IN THE NORTHERN GREAT PLAINS [1]

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INTRODUCTION

The term "water requirement" has been defined by Briggs and Shantz (*1*)[3] as the ratio of the weight of water absorbed by a plant during its growth to the weight of dry matter produced, exclusive of the roots.

The experiments reported in this paper were planned in connection with the more extensive investigations of the water requirement of plants under diverse climatic conditions as projected by the authors just cited. The writer's investigations also involved the determination of the water requirement of related strains of alfalfa, millet, and sorgo which he had selected for adaptation to dry-land conditions. These selections were grown in the experiments in order to determine (1) whether the water requirement can be used as a measure of the relative adaptation to conditions of drought of different varieties of the same crop, (2) whether similar varieties or selected progeny strains show appreciable differences in water requirement, and (3) whether the water requirement of crop plants is correlated with yields as determined by plot tests in the field.

These experiments were carried on for seven years, 1912 to 1918, inclusive, at the Belle Fourche Field Station, Newell, S. Dak., and for four years, 1919 to 1922, inclusive, at the United States Northern Great Plains Field Station, Mandan, N. Dak. The experiments at the Belle Fourche station were planned in consultation with T. H. Kearney of the Office of Alkali and Drought Resistant Crops, Bureau of Plant Industry, and H. L. Shantz, formerly of that office. In 1919 the experiments were transferred to Mandan, N. Dak. In 1921 the writer was transferred from the Office of Alkali and Drought Resistant Crops to the Office of Cereal Investigations (now the Office of Cereal Crops and Diseases), but continued the water-requirement investigations at Mandan in 1921 and 1922.[4]

A brief description of the climate, soil, and agricultural conditions in each locality is given under the headings for the respective stations.

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[3] Reference is made by number (italic) to Literature Cited, p. 238.

[4] The writer is greatly indebted to Beyer Aune, superintendent of the Belle Fourche Field Station, Office of Western Irrigation Agriculture, for cordial cooperation in furnishing labor during the course of the experiments at Newell, and to J. M. Stephens, superintendent of the United States Northern Great Plains Field Station, Office of Dry Land Agriculture, for equally generous cooperation at Mandan.

EXPERIMENTAL METHODS

The methods employed were essentially the same as those described by Briggs and Shantz (*1*). The plants were grown in large galvanized-iron pots having a capacity of about 115 kgm. of soil. The pots were fitted with tight covers sealed at the edges with tape coated with shellac. Holes were punched in the covers, through which the seedling plants emerged, the space surrounding the plants being sealed water-tight with wax. A larger hole in the middle of the cover was used for watering the plants. The cork stopper inserted in this hole was provided with a capillary tube of lead to equalize atmospheric pressure within and without the pot and thus prevent the entrance of water around the plants due to rapid cooling of the pot during showers.

The pot covers were of two types: (1) Those with 21 holes one-half inch in diameter, which were used for wheat, millet, flax, and other small-stemmed plants; and (2) those with 6 holes 1⅛ inches in diameter, which were used for alfalfa, sorgo, and the perennial grasses. The grasses having rootstocks were grown fairly successfully by confining the rootstocks to a limited space by means of metal cones placed beneath the covers. The galvanized-iron cones were about 4 inches long, 1⅛ inches in diameter at the upper end, and 3 inches in diameter at the lower end. These were set in the soil, the small end of the cone fitting into the hole in the cover, and the seedling grass plants were set in place. The rootstock by this means were forced to grow upward through the holes in the cover rather than to spread laterally in the surface soil just below the cover, as they naturally would do.

The pots were weighed with a spring balance of a capacity of 150 kgm., which was checked frequently against a known weight. The initial weight usually was not taken until the seedling plants had reached a height of 2 or 3 inches, when the plants were sealed in with wax and the weight of the pot recorded. The pots were weighed at frequent intervals, usually every second day in the early growth period and every day when the absorption of water was most rapid. Water was added from calibrated 2-liter flasks. The final weight was taken accurately to 0.1 kgm. immediately after the plants were harvested. The plants were cut off at the surface of the cover, except in the case of alfalfa. The alfalfa plants were clipped carefully so as to leave one or two growing buds at the base of each remaining stem, in order to promote quick revival of growth.

As a protection against birds and possible hail storms the plants were grown within a screened inclosure 20 feet wide, 40 feet long, and 9 feet high. This provided space for 96 pots arranged in four rows running east and west with board walks between. The inclosure was covered with ⅜-inch galvanized-wire mesh supported by iron pipes. The plants were protected from high winds by the board frame (3 feet high) of the inclosure and also by a strip of thin white muslin attached to the screen above the board frame. Briggs and Shantz (*1*) found that the water requirement of Kubanka wheat grown in pots sunk in trenches in a field of growing wheat was about 10 per cent higher than that of the same variety when grown within the shelter.

The soil used was always surface soil in good tilth, obtained from a plot that had been kept fallow the previous season. In order to

insure adequate fertility a fertilizer was added, composed of 25 parts per million of PO_4, 50 parts of NO_3, and 33 parts of K, all based on a dry weight of 100 kgm. of soil per pot. The phosphoric acid was applied as sodium phosphate and the nitrogen and potash as potassium nitrate. The fertilizer was dissolved in water and added in three or four portions during the gowing season. An application of 2 liters of the dilute solution was followed at once by 2 liters of water to prevent temporary wilting of the foliage.

GENERAL CLIMATIC CONDITIONS

The weather records of the Biophysical Laboratory, Bureau of Plant Industry, are available for study in connection with the water-requirement data. These records include daily precipitation; air temperature as recorded by a standardized thermograph; relative humidity; hourly wind velocity; and daily evaporation from the free water surface of a tank 8 feet in diameter and 2 feet deep, the water maintained at ground level, about 4 inches below the edge of the tank.

The general similarity of the climatic conditions at Newell, S. Dak., and at Mandan, N. Dak., during the period of the experiments is shown in Table 1, where the annual and seasonal precipitation and the seasonal evaporation are given for each year of the experiments and as averages for a long period at each station.

More detailed weather data are presented under the results at each station in a discussion of the relation between the seasonal weather conditions and the water requirement of the several crops.

TABLE 1.—*Annual and seasonal (April to August, inclusive) precipitation, and seasonal evaporation from a free water surface, 1912–1918 at Newell, S. Dak., and 1919–1922 at Mandan, N. Dak.*

Place and year	Precipitation		Evaporation, seasonal
	Annual	Seasonal	
Newell, S. Dak.:	*Inches*	*Inches*	*Inches*
1912	16.09	10.87	34.03
1913	12.53	5.94	32.43
1914	11.70	7.86	30.92
1915	21.02	15.82	23.50
1916	13.40	10.03	27.05
1917	13.32	9.66	29.51
1918	18.31	11.57	28.62
Mean for 20-year period, 1908 to 1927	16.24	11.06	30.02
Mandan, N. Dak.:			
1919	13.48	8.86	34.24
1920	12.69	8.64	30.60
1921	15.23	10.09	33.53
1922	17.35	9.63	29.03
Mean for 14-year period, 1914 to 1927	15.85	11.42	29.20

EXPERIMENTS AT NEWELL, S. DAK.

The Belle Fourche Field Station is located near Newell, about 30 miles northeast of the Black Hills, in western South Dakota. The latitude is about 44° 44′ N., the longitude 103° 26′ W. The altitude is 2,870 feet above sea level. The soil of this section is a heavy clay, locally known as "gumbo" and classified as Pierre clay (*12*). It consists of about 35 per cent of clay, 43 per cent of silt, and 13 per cent

of very fine sand. When wet, the soil is extremely sticky and takes up water very slowly. As it dries out it shrinks and forms great cracks which enable it to take up water rapidly during quick heavy rains and in irrigation.

As the soil is composed largely of clay and silt, it will hold a large quantity of water. It has a moisture equivalent of about 30 per cent, and its field-carrying capacity is also about 30 per cent, of which about half is available for the use of plants (*9*). Fortunately, plants do not appear to suffer from drought for some time after the soil begins to crack. It is possible, therefore, to irrigate, and in pot cultures to water the plants, after the soil becomes easily receptive of water and before the plants suffer from drought. This period, however, is not long, perhaps from two to five days in midsummer, when crops are making most rapid growth.

The native vegetation is chiefly of the short-grass type, with western wheatgrass (*Agropyron smithii*), buffalo grass (*Bulbilis dactyloides*), and grama grass (*Bouteloua gracilis*) predominating. Western wheatgrass is the typical grass of the gumbo soil of western South Dakota and is very prominent in creek and river valleys where occasional overflow occurs, and elsewhere in wet seasons.

The average annual precipitation at Newell for the 20-year period 1908 to 1927, inclusive, was 16.24 inches and ranged from 6.64 inches in 1911 to 27.37 inches in 1923. The average seasonal precipitation from April to August, inclusive, was 11.06 inches.

A summary of the seasonal (April to September, inclusive) climatic conditions from 1912 to 1918, inclusive, at Newell is given in Table 2.

TABLE 2.—*Summary of monthly (April to September, inclusive) climatic conditions, 1912–1918, at Newell, S. Dak.*

Year and month	Air temperature					Average wind velocity per hour	Precipitation	Evaporation
	Average daily—			Absolute—				
	Mean	Maximum	Minimum	Maximum	Minimum			
1912:	°F.	°F.	°F.	°F.	°F.	*Miles*	*Inches*	*Inches*
April	47	61	34	78	28	9.5	2.32	4.85
May	55	66	43	84	32	11.1	2.26	6.42
June	66	80	52	101	39	7.6	.29	8.17
July	70	83	57	94	40	6.0	3.20	7.98
August	68	81	55	95	47	6.9	2.80	6.60
September	52	63	41	94	24	7.6	3.49	3.71
Average or total	60	72	47			8.1	14.36	37.73
1913:								
April	48	62	35	89	24	6.2	.25	4.70
May	53	64	42	95	26	5.9	1.98	4.30
June	66	79	54	98	45	6.8	3.10	7.05
July	70	85	57	101	42	5.8	.35	8.23
August	74	89	59	104	45	5.1	.26	8.14
September	59	73	46	97	29	4.5	2.38	4.71
Average or total	62	75	49			5.7	.832	37.13
1914:								
April	43	56	33	78	8	8.2	1.09	3.37
May	55	68	44	85	30	7.7	2.22	5.13
June	65	80	53	98	44	6.7	2.09	6.71
July	76	92	60	104	48	5.0	1.34	8.74
August	69	84	53	102	40	5.0	1.12	6.97
September	62	79	47	101	35	6.2	.35	4.19
Average or total	62	77	48			6.5	8.21	35.11

TABLE 2.—*Summary of monthly (April to September, inclusive) climatic conditions, 1912–1918, at Newell, S. Dak.*—Continued

Year and month	Air temperature					Average wind velocity per hour	Precipitation	Evaporation
	Average daily—			Absolute—				
	Mean	Maximum	Minimum	Maximum	Minimum			
	°F.	°F.	°F.	°F.	°F.	*Miles*	*Inches*	*Inches*
1915:								
April	52	64	41	83	26	6.6	2.58	4.45
May	51	62	42	84	28	7.4	2.32	3.97
June	58	70	48	84	33	6.2	4.74	4.61
July	64	75	54	88	41	5.0	5.74	5.35
August	66	79	53	97	40	4.1	.44	5.11
September	56	69	43	100	30	5.9	1.26	3.96
Average or total	58	70	47			5.9	17.08	27.45
1916:								
April	42	54	30	73	17	7.8	.64	3.09
May	52	65	40	92	25	8.7	3.17	5.27
June	60	72	49	89	35	7.3	2.19	5.14
July	74	90	61	103	49	5.1	2.01	7.52
August	67	82	54	96	42	4.4	2.02	5.44
September	58	75	41	98	28	6.2	.20	5.43
Average or total	59	73	46			6.6	10.23	32.49
1917:								
April	40	50	30	74	19	7.8	2.51	2.02
May	50	62	38	91	28	5.7	3.71	4.70
June	62	76	47	100	36	6.3	.97	6.27
July	75	92	58	108	45	5.3	.80	9.54
August	67	82	52	100	39	4.2	1.67	6.98
September	60	76	45	88	34	5.1	.35	5.31
Average or total	59	73	45			5.7	10.01	34.82
1918:								
April	41	51	30	76	18	9.2	2.40	3.28
May	55	69	42	90	31	6.6	1.60	5.17
June	69	83	54	100	33	4.5	1.17	6.55
July	69	82	57	100	46	4.2	3.41	6.48
August	70	85	55	100	42	2.8	2.99	7.13
September	56	69	43	90	26	2.2	3.08	3.95
Average or total	60	73	47			4.9	14.65	32.56

It will be seen that the evaporation from a free water surface varied considerably from month to month and, with the exception of that for May, 1915, was greatest during the warm months of June, July, and August. The mean air temperature of the three summer months, June, July, and August, and the evaporation for the same period each year were as follows:

Year	1912	1913	1914	1915	1916	1917	1918
Temperature (°F.)	68	70	70	63	67	68	69
Evaporation (inches)	22.7	23.4	22.4	15.1	18.1	22.8	20.2

The lowest evaporation was recorded in the cool season of 1915.

As evaporation is a measure of the intensity of the several weather factors—temperature, humidity, solar radiation, and wind velocity—which also affect transpiration in varying degrees, as shown by Briggs and Shantz (*3*) and others, it is of interest to note the relation between evaporation and the water requirement of the several crops from year to year. For this purpose the evaporation for 5-day periods from April to September, inclusive, is shown in Table 3.

TABLE 3.—*Evaporation by 5-day periods from April to September, inclusive, 1912–1918, at Newell, S. Dak.*

Period (dates inclusive)	1912	1913	1914	1915	1916	1917	1918
April:	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1–5	0.965	0.488	0.767	0.814	0.463	0.220	0.333
6–10	.950	.477	.494	.767	.586	.296	.545
11–15	.629	.382	.736	.720	.702	.368	.839
16–20	.359	1.158	.580	.888	.630	.367	.443
21–25	.744	.992	.424	.351	.658	.591	.551
26–30	1.202	1.208	.368	.914	.650	.176	.567
Total	4.849	4.705	3.369	4.454	3.689	2.018	3.278
May:							
1–5	.710	.513	.841	.284	.851	.425	1.031
6–10	1.122	.716	.881	.761	1.227	1.047	.843
11–15	.866	.717	.602	1.092	.657	1.263	.777
16–20	1.138	.388	.803	.812	.625	.947	.965
21–25	.779	.777	.559	.531	.624	.460	.965
26–31	1.808	1.191	1.447	.490	1.285	.562	.590
Total	6.423	4.302	5.133	3.970	5.269	4.704	5.171
June:							
1–5	1.540	1.373	1.000	.510	.824	.530	.871
6–10	1.077	1.257	1.096	.700	1.106	1.025	1.127
11–15	1.033	1.194	1.738	.421	.569	1.084	1.160
16–20	1.073	.821	1.232	.912	.893	1.314	1.136
21–25	1.715	1.264	1.552	.918	.746	1.099	1.329
26–30	1.737	1.137	1.094	1.151	1.000	1.219	.932
Total	8.175	7.046	6.712	4.612	5.138	6.271	6.555
July:							
1–5	1.287	1.401	1.371	.758	1.336	1.604	1.476
6–10	1.272	1.555	1.224	.806	1.423	1.757	.705
11–15	1.419	1.580	1.797	.897	1.278	1.566	.917
16–20	.873	1.201	1.692	.843	1.052	1.339	.915
21–25	1.349	.963	1.270	.872	1.363	1.475	.997
26–31	1.780	1.535	1.383	1.176	1.067	1.795	1.472
Total	7.980	8.235	8.737	5.352	7.519	9.536	6.482
August:							
1–5	.679	1.240	1.437	.773	1.183	1.293	1.308
6–10	1.085	.945	1.461	.929	.869	.939	.960
11–15	1.241	1.523	1.181	.892	.541	1.054	1.054
16–20	.858	1.456	.865	.768	1.121	1.078	1.120
21–25	1.216	1.345	1.318	.808	.806	1.427	1.331
26–31	1.525	1.635	.704	.943	.918	1.192	1.356
Total	6.604	8.144	6.966	5.113	5.438	6.983	7.129
September:							
1–5	1.167	1.237	.610	.747	1.238	.791	.682
6–10	.903	.902	.543	.818	.879	.907	.718
11–15	.543	.871	.771	.484	.888	.986	.853
16–20	.399	.728	.514	.969	.922	.673	.605
21–25	.339	.568	.804	.639	.881	1.069	.578
26–30	.362	.401	.952	.349	.621	.881	.515
Total	3.713	4.707	4.194	3.956	5.429	5.307	3.951
Total for season	37.744	37.139	35.111	27.457	32.482	34.819	32.566

WATER REQUIREMENT OF CROP PLANTS

WHEAT

Kubanka wheat (*Triticum durum*), C. I. 1440,[5] was grown throughout the period of the experiments reported in this paper. As this variety is well adapted to the climatic conditions of the northern Great Plains it was used as a check on the results from year to year and for comparison with other crops. It was grown also in the experiments at Akron, Colo., as reported by Shantz and Piemeisel (*11*).

[5] Accession number of the Office of Cereal Crops and Diseases (formerly Office of Cereal Investigations).

The water requirement of Kubanka wheat for the seven years 1912 to 1918, at Newell, is shown in Table 4. Its mean water requirement, based on total dry matter, averaged 431 ± 5 for the 7-year period and ranged from 333 ± 2 in the cool and relatively rainy season of 1915 to 528 ± 5 in the warm, dry season of 1914. (Fig. 1.) Based on grain, the mean water requirement averaged 1,140 ± 29 and ranged from 920 ± 25 in 1915 to 1,279 ± 23 in 1914.

FIGURE 1.—Kubanka wheat grown in the water-requirement experiments at Newell, S. Dak. Photographed July 9, 1914

TABLE 4.—*Water requirement of Kubanka wheat (C. I. 1440), 1912–1918, at Newell, S. Dak.*

Year and period of growth	Pot No.	Dry matter	Grain		Water	Water requirement based on—	
						Grain	Dry matter
		Grams	*Grams*	*Per cent*	*Kgm.*		
1912: May 3 to Aug. 13 (102 days)	1	110.0	42.4	39	51.50	1,214	468
	2	151.2	65.8	44	68.18	1,038	452
	3	120.0	43.8	37	56.53	1,290	471
	4	129.8	53.2	41	61.57	1,156	474
	5	120.0	43.0	36	51.25	1,192	427
	6	100.7	34.3	34	49.12	1,433	488
Mean		122.0	47.1			1,221±36	463±6
1913: Apr. 21 to Aug. 1 (102 days)	1	90.0	41.4	46	40.4	976	449
	2	99.8	46.7	47	42.3	906	424
	3	89.6	38.8	44	38.0	980	427
	4	89.5	40.1	44	40.6	1,012	454
	5	88.3	39.7	45	38.4	968	435
	6	85.0	39.3	46	38.1	970	448
Mean		90.3	41.0			969±8	440±4
1914: May 1 to July 30 (90 days)	1	92.5	39.2	42	49.2	1,255	532
	2	95.4	41.6	44	49.8	1,197	522
	3	98.0	39.3	40	49.2	1,252	502
	4	88.9	35.8	40	49.2	1,374	553
	5	94.1	39.7	42	48.9	1,232	520
	6	90.7	35.8	40	48.9	1,366	539
Mean		93.3	38.6			1,279±23	528±5

TABLE 4.—*Water requirement of Kubanka wheat (C. I. 1440), 1912–1918, at Newell, S. Dak.*—Continued

Year and period of growth	Pot No.	Dry matter	Grain		Water	Water requirement based on—	
						Grain	Dry matter
		Grams	*Grams*	*Per cent*	*Kgm.*		
1915: May 14 to Aug. 25 (103 days)	1	118.0	44.4	38	39.0	878	330
	2	126.9	50.0	39	40.8	816	322
	3	125.5	46.3	37	41.6	900	331
	4	130.0	44.2	34	44.6	1,008	343
	5	134.8	50.0	37	44.4	888	330
	6	142.6	47.1	33	48.6	1,032	341
Mean		129.6	47.0			920±25	333±2
1916: Apr. 28 to July 31 (94 days)	1	151.9	47.6	31	50.6	1,063	333
	2	172.5	53.1	31	64.2	1,208	372
	3	139.0	43.2	31	48.9	1,132	352
	4	151.3	42.5	28	53.2	1,252	352
	5	128.5	36.4	28	49.8	1,368	388
	6	133.7	45.8	34	41.9	915	313
Mean		146.2	44.8			1,156±45	352±7
1917: May 24 to Aug. 18 (86 days)	1	108.5	42.3	39	53.5	1,265	493
	2	118.7	46.8	39	54.2	1,158	457
	3	102.6	39.7	39	51.0	1,285	500
	4	111.3	41.0	37	51.9	1,266	466
	5	124.5	47.5	38	62.0	1,305	498
	6	116.3	49.4	42	59.0	1,194	507
Mean		113.6	44.5			1,246±17	487±6
1918: May 15 to Aug. 14 (91 days)	1	83.6	26.1	31	37.6	1,440	450
	2	91.9	30.0	33	39.8	1,327	433
	3	112.1	39.6	35	47.6	1,202	424
	4	126.6	45.8	36	50.2	1,100	397
	5	122.2	46.7	38	48.4	1,036	396
	6	120.4	45.7	38	47.0	1,028	390
Mean		109.5	39.0			1,189±51	415±8

The close relationship between the water requirement and evaporation from a free water surface during the growth period of the crop may be observed. If the average water requirement for the period is expressed as 100, then the water-requirement determination for each year may be expressed as a percentage or as a relative figure. For comparison, the evaporation may be expressed in the same manner. The relation between the water requirement of Kubanka wheat and evaporation during the 3-month period from June to August, inclusive, is shown in Table 5.

TABLE 5.—*Annual water requirement of Kubanka wheat, and summer evaporation, 1912–1918, Newell, S. Dak.*

Year	Water requirement		Evaporation, June to August	
	Actual	Relative	Actual	Relative
			Inches	
1912	463	107	22.7	113
1913	436	101	[a] 19.6	98
1914	528	123	22.4	111
1915	333	77	15.1	75
1916	352	82	18.1	90
1917	487	113	22.8	113
1918	415	96	20.2	100
Average	431	100	20.1	100

[a] Evaporation May to July, inclusive, being the period covered by the crop grown in 1913.

It will be seen that the years 1912, 1914, and 1917 were years of high evaporation and high water requirement, while 1915 and 1916 were years of low evaporation and low water requirement.

Acre yields are influenced or determined by so many factors, as pointed out by Chilcott (*4*), that a close correlation can not be expected between water requirement and crop yields from year to year. It may be noted, however, that the years of low water requirement, 1915 and 1916, were years of favorable wheat yields, while in 1914 and 1917 the water requirement was high and the yields low. This subject is discussed at greater length on page 226, under the heading "Effect of Season on Water Requirement."

FIGURE 2.—Kursk millet, A. D. I. 3. Photographed August 28, 1915

MILLET

Five varieties or strains of millet (*Chaetochloa italica*) were grown for one or more seasons during the course of the experiments at Newell. The strain of Siberian millet, A. D. I. 4–3,[6] and the two strains of Kursk millet, A. D. I. 3 and A. D. I. 13–3, have orange-yellow seeds and belong to the same varietal group. The three strains mentioned were developed by the writer (*6*) by selection from mixed varieties introduced from Russia by the United States Department of Agriculture. (Fig. 2.) Common millet was grown in 1912, and Gold Mine, a larger type of Common millet, was grown from 1915 to 1917, inclusive. The water requirement of Kursk millet A. D. I. 3 for the seven years 1912 to 1918 is shown in Table 6. The water requirement of Siberian millet, A. D. I. 4–3, is shown in Table 7, and that of the Common, Kursk A. D. I. 13–3, and Gold Mine in Table 8.

[6] Accession number of the former Office of Alkali and Drought Investigations.

The water requirement of the five varieties or strains of millet grown during the 7-year period 1912 to 1918, inclusive, at Newell, S. Dak., is shown in Table 9.

TABLE 6.—*Water requirement of Kursk millet (A. D. I. 3), 1912–1918, at Newell, S. Dak.*

Year and period of growth	Pot No.	Dry matter	Grain		Water	Water requirement based on—	
						Grain	Dry matter
		Grams	*Grams*	*Per cent*	*Kgm.*		
1912: June 21 to Sept. 5 (76 days)	43	259.0	101.4	39	61.3	604	237
	44	223.7	79.9	36	54.3	682	243
	45	227.8	103.3	45	51.2	496	225
	46	226.1	94.5	42	52.3	554	231
	47	240.0	107.2	45	57.8	539	241
	48	242.0	106.0	44	62.1	585	256
Mean		236.4	98.7			577±18	239±3
1913: June 10 to Aug. 26 (77 days)	43	176.8	81.7	46	53.7	657	304
	44	220.0	101.1	46	67.6	669	307
	45	150.3	60.9	41	42.0	690	280
	46	188.8	84.7	45	54.9	648	291
	47	186.0	83.6	45	52.4	627	282
	48	203.7	88.3	43	59.3	672	291
Mean		187.6	83.4			661±6	293±3
1914: June 15 to Aug. 31 (77 days)	37	53.5			13.8		258
	38	44.5			13.1		294
	39	57.8			19.3		334
	40	49.2			16.4		333
	41	49.8			14.4		289
	42	55.2			19.6		355
Mean		51.7					311±11
1915: July 1 to Aug. 28 (58 days)	37	223.7	75.7	34	39.9	527	178
	38	245.2	80.2	33	42.4	529	173
	39	236.3	83.8	35	39.7	474	168
	40	229.2	81.7	36	38.6	472	168
	41	251.0	79.0	32	42.6	539	170
	42	262.0	88.0	34	43.6	495	166
Mean		241.2	81.4			506±10	171±1
1916: July 1 to Aug. 28 (58 days)	13	271.4	63.7	23	63.6	999	234
	14	271.4	53.7	23	62.3	978	230
	15	256.7	67.5	26	59.4	880	231
	16	287.2	70.8	25	66.6	941	232
	17	244.6	55.2	23	57.3	1,038	234
	18	250.1	67.3	27	59.3	881	236
Mean		263.6	64.7			953±10	233±1
1917: July 1 to Aug. 31 (61 days)	13	205.6			57.7		281
	14	168.0			46.5		277
	15	195.5	34.0	17	53.1	1,560	272
	16	174.5	20.6	12	49.0	2,380	281
	17	181.0	21.0	12	49.3	2,350	272
	18	193.8			55.5		286
Mean		186.4	25.2			2,096±214	278±2
1918: June 20 to Aug. 19 (60 days)	31	178.1	31.1	17	43.5	1,398	244
	32	171.6	37.3	22	39.9	1,070	233
	33	177.6	39.3	22	51.4	1,307	289
	34	180.4	49.2	27	42.2	858	234
	35	196.3	30.9	16	43.1	1,395	220
	36	198.7	43.3	22	43.3	1,000	218
Mean		183.8	38.5			1,171±74	239±7

TABLE 7.—*Water requirement of Siberian millet (A. D. I. 4–3), 1912–1917, at Newell, S. Dak.*

Year and period of growth	Pot No.	Dry matter	Grain		Water	Water requirement based on—	
						Grain	Dry matter
		Grams	*Grams*	*Per cent*	*Kgm.*		
1912: June 21 to Sept. 5 (76 days)	37	252.0	89.8	36	63.3	705	251
	38	245.7	93.0	38	63.3	681	258
	39	274.7	101.6	37	69.0	679	251
	40	290.0	113.4	39	69.6	614	240
	41	286.0	111.6	39	64.5	578	225
	42	263.0	75.1	29	62.5	832	238
Mean		268.6	97.4			682±22	244±4
1913: June 10 to Aug. 26 (77 days)	37	210.0	80.9	39	68.2	844	325
	38	193.6	69.0	36	63.6	922	328
	39	182.0	48.8	27	60.5	1,240	332
	40	197.8	74.0	37	62.0	838	313
	41	191.2	77.7	41	62.5	805	327
	42	189.0	74.2	39	62.3	840	330
Mean		193.9	70.8			915±42	326±2
1914: June 15 to Aug. 31 (77 days)	31	75.0			21.3		288
	32	85.8			24.8		289
	33	65.1			18.2		280
	34	90.5			30.1		333
	35	91.3			27.9		306
	36	95.2			30.8		324
Mean		83.8					303±7
1915: July 1 to Aug. 30 (60 days)	31	251.3	72.5	29	43.4	596	173
	32	244.0	73.1	30	41.2	564	169
	33	247.5	71.5	29	45.9	642	185
	34	244.7	70.6	29	44.0	623	180
	35	258.7	75.3	29	45.8	608	177
	36	253.8	72.5	29	44.7	617	176
Mean		250.0	72.6			608±8	177±2
1916: July 1 to Aug. 28 (58 days)	7	266.3	52.4	20	61.5	1,173	231
	8	245.7	50.9	21	52.2	1,025	212
	9	255.5	59.2	23	59.4	1,004	232
	10	220.0	43.9	20	49.9	1,137	227
	11	260.7	65.2	24	63.4	972	243
	12	259.7	55.3	21	63.4	1,146	244
Mean		251.3	54.5			1,076±29	231±3
1917: July 1 to Aug. 21 (61 days)	7	202.6	26.0	13	57.8	2,223	285
	8	223.1	35.0	16	60.9	1,740	273
	9	214.1	30.4	14	58.0	1,907	271
	10	193.0			55.0		285
	11	202.3			54.4		269
	12	198.8			53.8		271
Mean		205.7				1,957	275±2

TABLE 8.—*Water requirement of three varieties of millet at Newell, S. Dak.: Common in 1912; Kursk, A. D. I. 13–3, in 1912 and 1913; and Gold Mine, 1915–1917*

Plant and period of growth	Pot No.	Dry matter	Grain		Water	Water requirement based on—	
						Grain	Dry matter
		Grams	*Grams*	*Per cent*	*Kgm.*		
1912: June 21 to Sept. 14 (85 days): Common, A. D. I. 8	31	221.7	80.4	37	65.0	809	293
	32	227.9	96.9	43	69.5	718	305
	33	219.0	83.8	38	71.3	850	325
	34	208.2	85.7	41	65.6	766	315
	35	201.1	82.5	41	62.2	754	309
	36	209.6	84.8	41	63.3	746	302
Mean		214.6	85.7			774±14	308±4

TABLE 8.—*Water requirement of three varieties of millet at Newell, S. Dak.: Common in 1912; Kursk, A. D. I. 13–3, in 1912 and 1913; and Gold Mine, 1915–1917*—Continued

Plant and period of growth	Pot No.	Dry matter	Grain		Water	Water requirement based on—	
						Grain	Dry matter
		Grams	*Grams*	*Per cent*	*Kgm.*		
1912: June 21 to Sept. 5 (76 days):							
Kursk, A. D. I. 13–3	49	238.5	110.4	46	60.7	550	254
	50	233.5	108.7	47	59.9	550	256
	51	240.0	108.0	45	58.3	539	243
	52	252.3	113.2	45	63.2	558	251
	53	247.7	105.0	43	59.2	564	239
	54	264.1	118.7	45	61.5	522	233
Mean		246.0	110.5			547±4	246±3
1913: June 10 to Aug. 26 (77 days):							
Kursk, A. D. I. 13–3	31	188.2	80.9	43	61.1	754	324
	32	196.3	89.0	45	64.7	727	330
	33	183.6	86.0	47	59.6	693	325
	34	216.0	97.0	45	72.1	744	334
	35	177.8	77.2	43	56.7	735	319
	36	177.3	80.1	45	61.0	762	344
Mean		189.9	85.0			736±4	329±3
1915: July 1 to Sept. 1 (62 days):							
Gold Mine	85	211.1			38.3		181
	86	220.6	55.0	25	39.4	716	179
	87	208.0	48.5	23	38.9	802	187
	88	239.5	55.5	23	44.3	798	185
	89	210.6	50.0	23	38.2	764	181
	90	227.2	57.8	25	43.2	748	190
Mean		219.5	53.4			766±12	184±2
1916: July 1 to Sept. 1 (62 days).							
Gold Mine	19	305.3	36.9	12	70.0	1,896	229
	20	282.1	34.9	12	67.0	1,918	237
	21	298.1	43.5	15	68.7	1,580	230
	22	328.6	54.2	16	76.2	1,405	234
	23	309.1	44.9	15	72.2	1,607	233
	24	299.3	41.9	14	67.0	1,598	224
Mean		303.8	42.7			1,667±60	231±1
1917: July 1 to Sept. 7 (68 days):							
Gold Mine	19	180.3			50.5		280
	20	221.9	20.0	9	62.5	3,125	282
	21	207.4	19.5	9	57.9	2,970	279
	22	213.0	18.0	8	58.0	3,220	272
	23	208.8			59.7		286
	24	204.0			57.0		280
Mean		205.9				3,105	280±1

TABLE 9.—*Annual water requirement of five varieties of millet, 1912–1918, Newell, S. Dak.*

Plant	Annual water requirement							
	1912	1913	1914	1915	1916	1917	1918	Average
Kursk, A. D. I. 3	239±3	293±3	311±11	171±1	233±1	278±2	239±7	252±4
Siberian, A. D. I. 4–3	244±4	326±2	303±7	177±2	231±3	275±2	.....	[a] 259±3
Kursk, A. D. I. 13–3	246±3	329±3	.....	.....	.....	.....	.....	.....
Common	308±4	.....	.....	.....	.....	.....	.....	.....
Gold mine	.....	.....	.....	184±2	231±1	280±1	.....	.....
Average	259±3	316±3	307±9	177±2	232±2	278±2	239±7	.....

[a] Six-year average.

In 1912 the water requirement of Common millet (308 ± 4) was higher than that of the three other varieties grown. In 1913, Kursk, A. D. I. 3, gave a lower value (239 ± 3) than that of two other varieties grown. Except in these cases there was no significant difference in the water requirement of the varieties tested.

The water requirement of Kursk millet, A. D. I. 3, averaged 252 ± 4 for the 7-year period and ranged from 171 ± 1 in 1915 to 311 ± 11 in 1914. Siberian millet had a water requirement of 259 ± 3 for the 6-year period 1912 to 1917, inclusive.

Based on grain production, Kursk millet, A. D. I. 3, averaged 994 ± 55 and ranged from 506 ± 10 in 1915 to 2,096 ± 214 in 1917. The high figure in 1917 can be explained by the fact that the crop was harvested before the seed was fully mature. In weight of grain per pot Kursk millet weighed more than Kubanka wheat and also had a lower water requirement based on grain.

FIGURE 3.—Dakota Amber sorgo as grown in cultivated rows. Photographed in the field, with a net as background, August 22, 1914

SORGO AND SUDAN GRASS

Two varieties of sweet sorghum—Sorgo (*Sorghum vulgare*) and Sudan grass (*S. vulgare* var. *sudanense*)—were grown during the period 1915 to 1918 at Newell. The water requirement of Dakota Amber sorgo (Table 10), based on dry matter, averaged 252 ± 3 and ranged from 210 ± 4 in 1915 to 284 ± 3 in 1918. Seed matured in three of the four seasons, and the water requirement, based on grain, averaged 1,031 ± 50. (Fig. 3.)

Red Amber sorgo, a later and more leafy type than Dakota Amber, was grown for three years, 1915 to 1917. (Table 11.) Its water requirement, based on dry matter, averaged 227 ± 2. (Fig. 4.)

Sudan grass (Table 12) was grown for four years, 1915 to 1918. Its water requirement, based on dry matter, ranged from 272 ± 2 in 1915 to 344 ± 5 in 1917 and averaged 316 ± 4. The yield of seed was recorded only in 1915, when the water requirement, based on grain, was 2,000 ± 78.

FIGURE 4.—Sudan grass (at left) and Red Amber sorgo grown in the water-requirement experiments at Newell, S. Dak. Photographed September 8, 1917

TABLE 10.—*Water requirement of Dakota Amber sorgo, 1915–1918, at Newell, S. Dak.*

Year and period of growth	Pot No.	Dry matter	Grain		Water	Water requirement based on—	
						Grain	Dry matter
		Grams	*Grams*	*Per cent*	*Kgm.*		
1915: July 1 to Sept. 28 (89 days)	43	156.7	43.5	28	36.4	837	232
	44	223.8	51.6	23	49.9	967	223
	45	267.7	63.3	24	51.9	820	194
	46	272.4	90.7	33	52.7	581	194
	47	241.8	45.8	19	50.6	1,105	209
	48	253.7	66.3	26	52.3	789	206
Mean		236.0	60.2			850±46	210±4
1916: July 1 to Sept. 11 (72 days)	31	225.3	65.1	29	57.1	878	253
	32	287.3	76.8	27	67.6	880	235
	33	274.7	70.5	26	65.3	926	238
	34	302.6	87.4	29	71.5	818	236
	35	253.5	57.6	23	58.6	1,017	231
	36	285.7	79.7	28	68.1	855	239
Mean		271.5	72.9			896±19	239±2
1917: July 1 to Sept. 8 (68 days)	31	223.0	50.0	22	60.2	1,204	270
	32	202.5	37.0	18	54.8	1,480	271
	33	226.3	62.5	28	63.9	1,022	282
	34	227.0	37.0	16	63.7	1,720	280
	35	261.7	55.0	21	72.5	1,318	277
	36	167.5	.....	.....	44.8	.....	268
Mean		218.0	48.3			1,349±85	275±2
1918: June 25 to Aug. 30 (66 days)	85	171.3	.....	.....	47.8	.....	279
	86	134.9	.....	.....	37.2	.....	276
	87	109.2	.....	.....	31.8	.....	291
	88	97.6	.....	.....	27.4	.....	281
	89	137.7	.....	.....	38.0	.....	276
	90	117.4	.....	.....	35.2	.....	300
Mean		128.0	.....	.....	.....	.....	284±3

TABLE 11.—*Water requirement of Red Amber sorgo, 1915–1917, at Newell, S. Dak.*

Year and period of growth	Pot No.	Dry matter	Water	Water requirement based on dry matter
		Grams	*Kgm.*	
1915: July 1 to Sept. 28 (89 days)	49	260.4	55.2	209
	50	297.2	59.3	199
	51	320.4	64.2	198
	52	322.5	65.6	203
	53	257.4	53.8	209
	54	312.0	63.3	203
Mean		295.0		204±1
1916: July 1 to Sept. 11 (72 days)	37	359.3	85.3	237
	38	392.0	90.5	231
	39	317.1	76.1	240
	40	377.3	83.4	221
	41	365.8	86.9	238
	42	363.6	80.8	222
Mean		362.5		232±3
1917: July 1 to Sept. 8 (68 days)	37	274.0	66.5	243
	38	334.1	82.1	246
	39	292.6	72.1	248
	40	345.0	84.4	245
	41	299.1	75.9	253
	42	314.7	75.0	239
Mean		309.7		246±1

TABLE 12.—*Water requirement of Sudan grass, 1915–1918, at Newell, S. Dak.*

Year and period of growth	Pot No.	Dry matter	Grain		Water	Water requirement based on—	
						Grain	Dry matter
		Grams	*Grams*	*Per cent*	*Kgm.*		
1915: July 1 to Sept. 28 (89 days)	25	190.7	28.7	15	51.6	1,798	271
	26	208.7	28.4	14	55.3	1,946	265
	27	191.9	22.7	12	52.2	2,300	272
	28	165.0	24.7	15	45.5	1,843	276
	29	213.2	24.7	12	57.2	2,315	268
	30	189.3	29.7	16	53.3	1,795	282
Mean		193.1	26.5			2,000±78	272±2
1916: July 1 to Sept. 11 (72 days)	25	314.2			101.3		322
	26	258.2			87.1		337
	27	313.0			93.0		297
	28	281.7			90.3		321
	29	280.5			85.3		304
	30	277.3			84.9		306
Mean		287.5					314±5
1917: July 1 to Sept. 8 (68 days)	25	203.8			70.2		345
	26	212.3			75.5		355
	27	195.7			71.0		363
	28	199.8			63.1		316
	29	208.7			69.9		335
	30	202.1			71.2		352
Mean		203.7					344±5
1918: June 25 to Aug. 30 (66 days)	25	166.8			54.7		328
	26	166.2			55.5		334
	27	154.7			53.9		348
	28	173.7			55.6		320
	29	171.0			55.6		325
	30	164.0			55.8		340
Mean		166.1					333±3

The average water requirement of Red Amber sorgo (227 ± 2) was the same as Kursk millet (Table 6) for the three years 1915 to 1917, inclusive. Dakota Amber sorgo required somewhat more water (252 ± 3) than Kursk millet (230 ± 3) per unit of dry matter produced during the 4-year period 1915 to 1918, inclusive. Sudan grass required about 37 per cent more water than millet and 25 per cent more water than Dakota Amber sorgo per unit of dry matter produced.

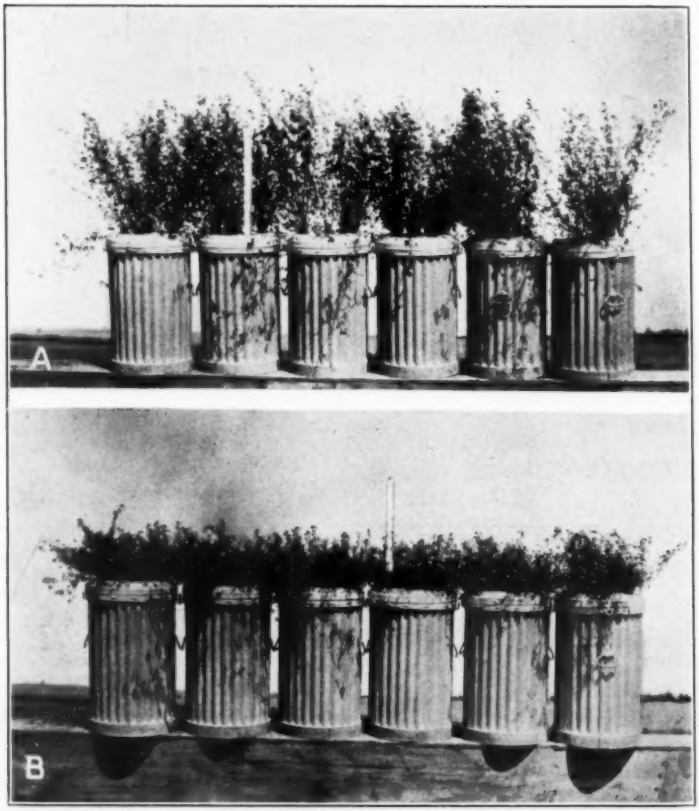

FIGURE 5.—A, Second crop of Turkestan alfalfa, A. D. I. F12-36, overwintered from the planting made in 1914; B, yellow-flowered alfalfa. *Medicago falcata*. Both photographed just before harvesting the second crop of the season, August 4, 1915, Newell, S. Dak.

At Akron, Colo., Shantz and Piemeisel (*11*) found that during the years 1911 to 1917, inclusive, the water requirement of Kursk millet was the same as that of Minnesota Amber sorgo (274 ± 3) and that the water requirement of Sudan grass (380 ± 3) was nearly 39 per cent higher than that of millet and sorgo.

Alfalfa

Nine varieties and strains of common alfalfa (*Medicago sativa*) and the yellow-flowered alfalfa (*M. falcata*) were grown in the water-requirement experiments at Newell, S. Dak., during the 7-year period 1912 to 1918, inclusive. Generally two or three crops were obtained each year, the plants being cut when in the early flowering stage, that is, in about the proper stage of growth for hay. The yield was not large, the total weight of dry matter ranging from about 50 to 200 gm. per pot. (Fig. 5.)

The water requirement of Grimm alfalfa, A. D. I. E–23, is shown in Table 13. The value shown in the last column represents a mean of six pots, except as otherwise noted, determined individually in each experiment.

The water requirement of the combined crop averaged 814 ± 14 and ranged from 696 ± 18 in 1915 to 1,038 ± 25 in 1914. In nearly every case the early-summer crop was produced with a lower water requirement than the midsummer crop and the midsummer more economically than the late-summer crop. This difference was marked in 1913, when the plants overwintered from the planting in 1912.

Table 13.—*Water requirement of Grimm alfalfa (A. D. I. E–23), 1912–1918, at Newell, S. Dak.*

Year and crop	Period of growth	Days of growth	Pot Nos. (inclusive)	Dry matter (average of 6 pots)	Water transpired (average of 6 pots)	Water requirement based on dry weight
		Number		*Grams*	*Kgm.*	
1912 (from seed):						
Midsummer	June 22 to Aug. 8	47	7–12	38.4	26.9	699±15
Late summer	Aug 8 to Sept. 24	47	7–12	38.0	29.1	772±18
Combined crop	June 22 to Sept. 24	94	7–12	76.3	55.9	735±15
1913 (planted in 1912):						
Early summer	Apr. 30 to June 30	61	7–12	36.6	17.2	469±6
Midsummer	June 30 to Aug. 6	37	7–12	27.0	21.9	817±13
Late summer	Aug. 6 to Sept. 18	43	7–12	20.3	22.6	1,115±16
Combined crop	Apr. 30 to Sept. 18	141	7–12	83.8	61.7	735±8
1914 (from seed):						
Midsummer	June 25 to Aug. 5	41	55–60	22.6	19.8	877±25
Late summer	Aug. 5 to Oct. 1	57	55–60	32.7	37.3	1,153±35
Combined crop	June 25 to Oct. 1	98	55–60	55.2	57.1	1,038±25
1914 (one pot, planted in 1912):						
Early summer	May 26 to June 25	30	25	43.8	23.6	539
Mid to late summer	June 25 to Sept. 2	69	25	43.4	34.7	800
Combined crop	May 26 to Sept. 2	99	25	87.2	58.3	669
1915 (from seed):						
Midsummer	July 1 to Aug. 5	35	73–78	32.0	14.0	442±14
Late summer	Aug. 5 to Sept. 20	46	73–78	58.6	48.5	836±19
Combined crop	July 1 to Sept. 20	81	73–78	90.7	62.5	696±18
1915 (planted in 1914):						
Early summer	Apr. 27 to June 30	64	55–60	57.4	24.3	424±9
Midsummer	June 30 to Aug. 5	36	55–60	66.5	27.3	413±7
Late summer	Aug. 5 to Sept. 20	46	55–60	77.1	48.3	630±18
Combined crop	Apr. 27 to Sept. 30	146	55–60	200.9	99.9	499±7
1916 (from seed):						
Midsummer	July 1 to July 26	25	85–90	34.8	21.8	622±11
Late summer	July 26 to Sept. 1	37	85–90	40.6	36.6	738±8
Autumn	Sept. 1 to Oct 2	31	85–90	29.1	18.0	621±12
Combined crop	July 1 to Oct. 2	93	85–90	113.4	76.4	673±8

TABLE 13.—*Water requirements of Grimm alfalfa (A. D. I. E.–23). 1912–1918 at Newell, S. Dak.*—Continued

Year and crop	Period of growth	Days of growth	Pot Nos. (inclusive)	Dry matter (average of 6 pots)	Water transpired (average of 6 pots)	Water requirement based on dry weight
		Number		*Grams*	*Kgm.*	
1917 (from seed):						
Midsummer	July 1 to July 31	30	85–90	32.6	26.2	811±16
Late summer	July 31 to Sept. 19	50	85–90	78.3	69.5	892±18
Combined crop	July 1 to Sept. 19	80	85–90	110.8	95.8	866±16
1918 (from seed):						
Midsummer	June 25 to Aug. 19	55	73–78	31.1	30.5	985±21
Late summer	Aug. 19 to Oct. 2	44	73–78	20.4	18.4	910±21
Combined crop	June 25 to Oct. 2	99	73–78	51.4	49.0	955±10
1918 (from seed):						
Crop grown for seed	do	99	79–84	44.2	61.9	1,399±14

In Table 14 is presented the water requirement of eight varieties and strains of alfalfa grown in the experiments at Newell, S. Dak. Five of these are progeny strains of the second, third, or fourth generation, selected by the writer for the purpose of improving the forage and seed-producing characters and for adaptation to drought.

The water requirement of the varieties grown for two or more years, based on the total annual crop, in comparison with Grimm, A. D. I. E–23, is shown in Table 15.

TABLE 14.—*Water requirement of varieties and selected strains of alfalfa, 1912–1918, at Newell, S. Dak.*

Variety, year, and crop	Period of growth	Days of growth	Pot Nos. (inclusive)	Dry matter (average of 6 pots)	Water transpired (average of 6 pots)	Water requirement based on dry weight
		Number		*Grams*	*Kgm.*	
Grimm, A. D. I. E–23–20–52:						
1912 (from seed)—						
Midsummer	June 22 to Aug. 8	47	19–24	39.1	25.3	646±10
Late summer	Aug. 8 to Sept. 24	47	19–24	44.1	27.7	630±8
Combined crop	June 22 to Sept. 24	94	19–24	83.2	53.0	638±5
1913 (planted in 1912)—						
Early summer	Apr. 30 to June 30	61	19–24	25.5	11.3	438±11
Midsummer	June 30 to Aug. 6	37	19–24	22.4	19.4	872±19
Late summer	Aug. 6 to Sept. 18	43	19–24	21.0	22.1	1,081±47
Combined crop	Apr. 30 to Sept. 18	141	19–24	68.9	52.8	766±12
Grimm, A. D. I. E–2–33–72:						
1912 (from seed)—						
Midsummer	June 22 to Aug. 8	47	13–18	31.5	23.9	755±19
Late summer	Aug. 8 to Sept. 24	47	13–18	37.7	26.8	712±9
Combined crop	June 22 to Sept. 24	94	13–18	69.2	50.7	731±12
1913 (planted in 1912)—						
Early summer	Apr. 30 to June 30	61	13–18	36.8	17.7	478±9
Midsummer	June 30 to Aug. 6	37	13–18	24.3	22.1	915±26
Late summer	Aug. 6 to Sept. 18	43	13–18	22.7	25.1	1,108±6
Combined crop	Apr. 30 to Sept. 18	141	13–18	83.8	64.9	775±9

TABLE 14.—*Water requirement of varieties and selected strains of alfalfa, 1912–1918, at Newell, S. Dak.*—Continued

Variety, year, and crop	Period of growth	Days of growth	Pot Nos. (inclusive)	Dry matter (average of 6 pots)	Water transpired (average of 6 pots)	Water requirement based on dry weight
		Number		*Grams*	*Kgm.*	
Grimm, A. D. I. E–5–30:						
1914 (from seed)—						
Midsummer	June 4 to Aug. 5	62	61–66	10.3	10.2	993±46
Late summer	Aug. 5 to Oct. 1	57	61–66	22.9	23.2	1,018±18
Combined crop	June 4 to Oct. 1	119	61–66	33.4	33.4	1,005±24
1915 (planted in 1914)—						
Early summer	Apr. 27 to June 30	64	61–66	54.0	25.0	464±8
Midsummer	June 30 to Aug. 5	36	61–66	62.1	24.8	400±4
Late summer	Aug. 5 to Sept. 20	46	61–66	75.8	46.3	611±13
Combined crop	Apr. 27 to Sept. 20	146	61–66	191.9	96.0	501±6
1916 (from seed)—						
Midsummer	July 1 to July 26	25	67–72	29.3	18.5	643±8
Late summer	July 26 to Sept. 1	37	67–72	40.3	32.0	794±14
Autumn	Sept. 1 to Oct. 2	31	67–72	24.5	17.2	697±20
Combined crop	July 1 to Oct. 2	93	67–72	94.0	67.6	718±11
1917 (from seed)—						
Midsummer	July 1 to July 31	30	73–78	25.9	21.5	833±9
Late summer	July 31 to Sept. 19	50	73–78	69.4	64.7	937±20
Combined crop	July 1 to Sept. 19	80	73–78	95.2	86.2	908±16
1918 (from seed)—						
Midsummer	June 25 to Aug. 19	55	55–60	22.6	24.2	1,097±40
Late summer	Aug. 19 to Oct. 2	44	55–60	18.2	17.0	941±8
Combined crop	June 25 to Oct. 2	99	55–60	40.7	41.2	1,023±24
Baltic, A. D. I. H–4–58:						
1914 (from seed)—						
Midsummer	June 4 to Aug. 5	62	19–24	9.8	10.6	1,090±37
Late summer	Aug. 5 to Oct. 1	57	19–24	20.2	21.3	1,039±31
Combined crop	June 4 to Oct. 1	119	19–24	30.0	31.8	1,066±25
1915 (planted 1914)—						
Early summer	Apr. 27 to June 30	64	19–24	48.6	24.9	515±11
Midsummer	June 30 to Aug. 5	36	19–24	55.8	24.9	448±9
Late summer	Aug. 5 to Sept. 20	46	19–24	61.4	41.8	683±12
Combined crop	Apr. 27 to Sept. 20	146	19–24	165.8	91.6	554±10
1916 (from seed)—						
Midsummer	July 1 to July 26	25	49–54	29.9	19.7	668±15
Late summer	July 26 to Sept. 1	37	49–54	42.5	32.1	756±17
Autumn	Sept. 1 to Oct. 2	31	49–54	26.3	17.3	656±4
Combined crop	July 1 to Oct. 2	93	49–54	98.7	69.1	700±13
1917 (from seed)—						
Midsummer	July 1 to July 31	30	55–60	33.3	27.3	824±14
Late summer	July 31 to Sept. 19	50	55–60	78.0	70.6	907±11
Combined crop	July 1 to Sept. 19	80	55–60	111.2	97.9	881±9
1918 (from seed)—						
Midsummer	June 25 to Aug. 19	55	37–42	37.8	34.1	910±27
Late summer	Aug. 19 to Oct. 2	44	37–42	23.2	18.6	807±15
Combined crop	June 25 to Oct. 2	99	37–42	61.0	52.7	871±15
Turkestan, A.D.I. F–12–36:						
1914 (from seed)—						
Midsummer	June 4 to Aug. 5	62	7–12	29.9	36.2	1,214±14
Late summer	Aug. 5 to Oct. 1	57	7–12	28.8	34.7	1,207±18
Combined crop	June 4 to Oct. 1	119	7–12	58.7	70.9	1,210±16

TABLE 14.—*Water requirement of varieties and selected strains of alfalfa, 1912–1918, at Newell, S. Dak.*—Continued

Variety, year, and crop	Period of growth	Days of growth	Pot Nos. (inclusive)	Dry matter (average of 6 pots)	Water transpired (average of 6 pots)	Water requirement based on dry weight
		Number		*Grams*	*Kgm.*	
Turkestan, A.D.I. F-12-36:—Con.						
1915 (from seed)—						
Midsummer	July 1 to Aug. 5	35	67–72	33.7	14.4	426±4
Late summer	Aug. 5 to Sept. 20	46	67–72	51.2	44.9	881±11
Combined crop	July 1 to Sept. 20	81	67–72	84.9	59.3	695±12
1915 (planted in 1914)—						
Early summer	Apr. 27 to June 30	64	7–12	70.4	30.2	431±5
Midsummer	June 30 to Aug. 5	36	7–12	70.2	29.8	425±3
Late summer	Aug. 5 to Sept. 20	46	7–12	74.6	48.5	651±7
Combined crop	Apr. 27 to Sept. 20	146	7–12	215.2	108.5	505±3
1916 (from seed)—						
Midsummer	July 1 to July 26	25	61–66	29.7	17.9	604±6
Late summer	July 26 to Sept. 1	37	61–66	41.0	29.0	711±17
Autumn	Sept. 1 to Oct. 2	31	61–66	22.5	14.4	642±19
Combined crop	July 1 to Oct. 2	93	61–66	93.2	61.3	659±9
1917 (from seed)—						
Midsummer	July 1 to July 31	30	61–66	32.7	27.7	847±10
Late summer	July 31 to Sept. 19	50	61–66	74.9	68.7	917±11
Combined crop	July 1 to Sept. 19	80	61–66	107.7	96.4	896±9
1918 (from seed)—						
Midsummer	June 25 to Aug. 19	55	61–66	26.5	25.5	961±24
Late summer	Aug. 19 to Oct. 2	44	61–66	19.1	17.3	903±23
Combined crop	June 25 to Oct. 2	99	61–66	45.6	42.7	937±23
Grimm, A.D.I. 81:						
1915 (from seed)—						
Midsummer	July 1 to Aug. 5	35	79–84	36.3	14.6	400±9
Late summer	Aug. 5 to Sept. 20	46	79–84	59.7	49.1	828±10
Combined crop	July 1 to Sept. 20	81	79–84	96.0	63.7	667±7
1916 (from seed)—						
Midsummer	July 1 to July 26	25	79–84	24.4	16.8	697±15
Late summer	July 26 to Sept. 1	37	79–84	40.2	29.4	738±28
Autumn	Sept. 1 to Oct. 2	31	79–84	23.7	16.3	696±30
Combined crop	July 1 to Oct. 2	93	79–84	88.4	62.5	713±20
1917 (from seed)—						
Midsummer	July 1 to July 31	30	79–84	24.5	22.6	940±25
Late summer	July 31 to Sept. 19	50	79–84	67.3	63.0	939±15
Combined crop	July 1 to Sept. 19	80	79–84	91.8	85.6	938±17
Grimm, A.D.I. 62:						
1916 (from seed)—						
Midsummer	July 1 to July 26	25	55–60	27.9	17.6	635±14
Late summer	July 26 to Sept. 1	37	55–60	36.4	27.3	752±9
Autumn	Sept. 1 to Oct. 2	31	55–60	21.1	14.9	707±19
Combined crop	July 1 to Oct. 2	93	55–60	85.4	59.7	701±9
Common (Kansas grown):						
1916 (from seed)—						
Midsummer	July 1 to July 26	25	73–78	36.4	21.5	594±14
Late summer	July 26 to Sept. 1	37	73–78	47.0	32.2	690±20
Autumn	Sept. 1 to Oct. 2	31	73–78	27.8	16.0	581±15
Combined crop	July 1 to Oct. 2	93	73–78	111.2	69.7	619±9

TABLE 15.—*Annual water requirement of seven varieties of alfalfa for two or more years, 1912–1918, at Newell, S. Dak.*

Plant	Annual water requirement							
	1912	1913	1914	1915	1916	1917	1918	Average
Grimm, A. D. I. E–23	735±15	[a] 735± 8						[b] 735±11
Grimm, A. D. I. E–23–20–52	638± 5	[a] 766±12						[b] 702± 8
Grimm, A. D. I. E–2–33–72	731±12	[a] 775± 9						[b] 753±10
Grimm, A. D. I. E–23			1,038±25	[a] 499± 7	673± 8	866±16	955±10	[c] 806±13
Grimm, A. D. I. E–5–30			1,005±24	[a] 501± 6	718±11	908±16	1,023±24	[c] 831±16
Baltic, A. D. I. H–4–58			1,066±25	[a] 654±10	700±13	881± 9	871±15	[c] 814±14
Turkestan, A. D. I. F–12–36			1,210±16	[a] 505± 3	659± 9	896± 9	937±23	[c] 841±12

[a] Plants overwintered. [b] 2-year average. [c] 5-year average.

In the 2-year period 1912 and 1913, Grimm, A. D. I. E–23–20–52 had a water requirement of 702 ± 8 as compared with 735 ± 11 for A. D. I. E–23 and 753 ± 10 for A. D. I. E–2–33–72. These differences are hardly significant. For the 5-year period 1914–1918, Grimm, A. D. I. E–23, had the lowest water requirement (806 ± 13) of the four varieties grown, but again the differences probably are not significant when the probable error is taken into account.

Common alfalfa, Kansas seed, was grown in 1916. (Table 14.) Its water requirement was 619 ± 9 as compared with 673 ± 8 for Grimm A. D. I. E–23.

In purchasing seed for planting, many farmers prefer seeds grown on dry land or under natural conditions of rainfall to those grown under irrigation. In order to determine whether irrigation has any immediate effect on the water requirement of alfalfa, the writer obtained seed of Grimm alfalfa, A. D. I. 81, which had been grown under irrigation at Rocky Ford, Colo., for three years and through two seed generations. This was grown in the water-requirement experiments for three years, 1915 to 1917, inclusive. (Table 14.) The water requirement of this strain, A. D. I. 81, averaged 773 ± 15 as compared with 745 ± 14 for Grimm, A. D. I. E–23 (Table 13), which had been grown continuously under dry-land conditions. The difference probably is not significant when the high probable error is considered. The water requirement of A. D. I. 81 was lower than that of A. D. I. E–23 in the cool season of 1915 but higher in the warmer seasons of 1916 and 1917.

YELLOW-FLOWERED ALFALFA

Yellow-flowered alfalfa (*Medicago falcata*) was grown for four years, 1912 to 1915, inclusive. (Table 16.) This species grows slowly during the first year from seed, but makes a rapid growth for the first crop the second season, with an economical use of water. It is slow to recover after cutting, and therefore the late summer crop shows a higher water requirement. (Fig. 5, B.) The species is very winter hardy, and it was possible to carry the plants over winter in the pots without winterkilling.

The water requirement of *Medicago falcata* averaged 617 ± 13 during the four years 1912 to 1915, as compared with 660 ± 10 for Grimm A. D. I. E–23 (*M. sativa*). (Table 13.)

TABLE 16.—*Water requirement of yellow-flowered alfalfa (S. P. I.[a] 28070) 1912–1915, at Newell, S. Dak.*

Year and crop	Period of growth	Days of growth	Pot Nos. (inclusive)	Dry matter (average)	Water transpired (average)	Water requirement based on dry matter
		Number		*Grams*	*Kgm.*	
1912 (from seed):						
Midsummer	July 3 to Aug. 8	36	25–30	21.6	13.0	624±15
Late summer	Aug. 8 to Sept. 24	47	25–30	15.0	10.7	736±18
Combined crop	July 3 to Sept. 24	83	25–30	36.6	23.7	662±12
1913 (planted in 1912):						
Early summer	Apr. 30 to June 30	61	25–30	53.0	18.2	340±7
Midsummer	June 30 to Aug. 6	37	25–30	27.5	19.6	713±11
Late summer	Aug. 6 to Sept. 18	43	25–30	15.7	18.6	1,220±52
Combined crop	Apr. 30 to Sept. 18	141	25–30	96.2	56.4	579±12
1914 (planted in 1912):						
Early summer	May 7 to June 24	48	26–30	37.1	17.4	503±38
Mid to late summer	June 24 to Sept. 2	70	26–30	29.6	27.6	930±26
Combined crop	May 7 to Sept. 2	118	26–30	66.7	45.0	687±20
1914 (from seed):						
Midsummer	June 25 to Aug. 5	41	13–18	11.3	13.7	1,225±26
Late summer	Aug. 5 to Oct. 1	57	13–18	9.4	17.2	1,837±34
Combined crop	June 25 to Oct. 1	98	13–18	20.7	30.9	1,500±20
1915 (planted in 1914):						
Early summer	Apr. 27 to June 30	64	13–18	58.3	23.0	399±8
Midsummer	June 30 to Aug. 5	36	13–18	36.7	15.5	424±4
Late summer	Aug. 5 to Sept. 20	46	13–18	22.4	24.7	1,108±20
Combined crop	Apr. 27 to Sept. 20	146	13–18	117.4	62.2	541±9

[a] Accession number of the Office of Foreign Plant Introduction (formerly Seed and Plant Introduction).

BROMEGRASS AND WHEATGRASSES

Three perennial grasses, bromegrass (*Bromus inermis*), crested wheatgrass (*Agropyron cristatum*), and western wheatgrass (*A. smithii*) were grown for two or more years in the water-requirement experiments at Newell. As mentioned under "Experimental Methods," the stems and rhizomes of the perennial grasses were forced to grow through the holes in the metal covers by means of a cone-shaped funnel placed around the crown of each plant below the cover. Two cuttings were made each year except in 1913, when only one crop of western wheatgrass was obtained. In Table 17 the water requirement of each species is shown.

TABLE 17.—*Water requirement of bromegrass (S. P. I. 29880), of crested wheatgrass (S. P. I. 19537), and of western wheatgrass, 1913–1918, at Newell, S. Dak.*

Species, year, and crop	Period of growth	Days of growth	Pot Nos. (inclusive)	Dry matter (average)	Water transpired (average)	Water requirement based on dry matter
		Number		*Grams*	*Kgm.*	
Bromegrass:						
1913 (from seed)—						
Midsummer	May 24 to July 18	55	61–66	15.8	15.9	1,025±27
Late summer	July 18 to Sept. 22	66	61–66	33.9	26.5	791±30
Combined crop	May 24 to Sept. 22	121	61–66	49.7	42.4	852±26
916 (from seed)—						
Midsummer	July 1 to Aug. 28	58	43–48	60.9	40.1	661±15
Late summer	Aug. 28 to Oct. 2	35	43–48	18.7	16.2	871±30
Combined crop	July 1 to Oct. 2	93	43–48	79.6	56.3	708±13
1917 (planted in 1916)—						
Midsummer	June 18 to July 30	42	43–48	35.2	32.7	939±22
Late summer	July 30 to Sept. 19	51	43–48	26.2	23.3	909±49
Combined crop	June 18 to Sept. 19	93	43–48	61.4	56.0	921±33
1918 (from seed)—						
Midsummer	June 12 to Aug. 19	68	43–48	30.4	21.4	704±16
Late summer	Aug. 19 to Oct. 2	44	43–48	16.6	10.7	645±14
Combined crop	June 12 to Oct. 2	112	43–48	47.0	32.1	684±14
Crested wheatgrass:						
1913 (from seed)—						
Midsummer	May 24 to July 18	55	49–54	25.8	16.3	633±9
Late summer	July 18 to Sept. 22	66	49–54	32.2	34.7	1,083±32
Combined crop	May 24 to Sept. 22	121	49–54	58.0	51.0	880±10
1914 (planted in 1913, 3 pots only)—						
Early summer	May 21 to June 24	34	51–53	24.7	10.6	422±13
Midsummer to late summer	June 24 to Sept. 30	98	51–53	24.8	39.9	1,705±195
Combined crop	May 21 to Sept. 30	132	51–53	49.5	50.5	1,024±34
Western wheatgrass:						
1913 (from seed)—						
Summer (one crop only)	May 24 to Sept. 22	121	55–60	28.6	35.9	1,247±31
1914 (planted in 1913, 1 pot only)—						
Early summer	May 21 to June 24	34	54	20.0	11.0	550
Midsummer to late summer	June 24 to Sept. 30	98	54	18.1	43.1	2,380
Combined crop	May 21 to Sept. 30	132	54	38.1	54.1	1,420

The water requirement of bromegrass averaged 791 ± 21 for the four years 1913 and 1916 to 1918, inclusive. Its lowest value was 684 ± 14 in 1918, and its highest value was 921 ± 33 in 1917.

Crested wheatgrass had a water requirement of 880 ± 10 in 1913 and 1,024 ± 34 in 1914. Its water requirement was higher than that of bromegrass (852 ± 26) in 1913, the only year in which both were grown. The low water requirement (422 ± 13) for the early-summer crop in 1914 and the high value (1,705 ± 195) for the mid-to-late summer crop are due to its habit of growth. This grass normally produces only one crop very early in the season and recovers slowly, making sparse growth during the summer and autumn. It is like yellow-flowered alfalfa in this respect.

Western wheatgrass produced a small crop, 28.6 gm. of dry matter per pot, with a high water requirement, 1,247 ± 31, in 1913. One pot overwintered gave a value of 1,420 in 1914.

Sugar Beet

One variety of sugar beet (*Beta vulgaris*), Kleinwanzleben, was grown in 1918. The plants made normal growth, the weight of fresh roots being 653 gm. (23.1 ounces) per pot. The water requirement based on total dry matter including tops was 304 ± 6. (Table 18.) The value based on the weight of dry roots was 451 ± 18.

Table 18.—*Water requirement of Kleinwanzleben sugar beet at Newell, S. Dak., in 1918*

Period of growth	Pot No.	Dry matter	Roots (dry)		Water	Water requirement based on—	
						Roots (dry)	Dry matter
		Grams	*Grams*	*Per cent*	*Kgm.*		
June 15 to Oct. 9 (116 days)	49	169.6	109.3	65	50.6	463	298
	50	150.3	100.5	67	47.6	474	317
	51	181.0	129.0	71	51.4	399	284
	52	165.3	101.0	61	56.5	560	342
	53	192.6	139.2	72	57.7	414	300
	54	203.1	146.2	72	57.9	396	285
Mean		177.0	120.9			451 ± 18	304 ± 6

EXPERIMENTS AT MANDAN, N. DAK.

The experiments on the water requirement of crop plants were continued at the United States Northern Great Plains Field Station, Mandan, N. Dak., from 1919 to 1922. This station is located 2 miles south of Mandan, Morton County, near the confluence of the Heart River with the Missouri, approximately in latitude 46° 50′ N. and longitude 100° 55′ W. The altitude at the field station is about 1,750 feet. The soil of the region is a brown to black loam derived from glacial till. The native vegetation is a mixture of the tall-grass and short-grass types, the latter generally predominating. According to Sarvis (*10*) the dominant species in the native vegetation are grama grass (*Bouteloua gracilis*), needle-and-thread grass (*Stipa comata*), and two small early sedges, *Carex filifolia* and *C. heliophila*. Many other grasses, including *Koeleria cristata*, *Agropyron smithii*, *A. tenerum*, *Andropogon scoparius*, *Stipa viridula*, *S. spartea*, and a variety of dicotyledons make a rich and varied flora.

The climate at Mandan is very similar to that at Newell. Although Mandan is approximately 2 degrees north of Newell, its altitude is 1,100 feet lower. The difference in soil between the two areas is most significant, the lighter loam soils at Mandan apparently being more favorable for native vegetation and for agricultural crops than the heavy clay soils at Newell.

The average annual precipitation at Mandan is approximately 16 inches (see Table 1) and the seasonal rainfall (April to August, inclusive) 11.4 inches. Table 19 shows a summary of the weather conditions for the six months April to September, inclusive, during the four years of the experiments, 1919 to 1922. The evaporation, by 5-day periods during the same months, is shown in Table 20. The relation of evaporation to the water requirement is discussed later in this paper.

TABLE 19.—*Summary of monthly (April to September, inclusive) climatic conditions, 1919–1922, at Mandan, N. Dak.*

Year and month	Air temperature					Average wind velocity per hour	Precipitation	Evaporation
	Average daily—			Absolute—				
	Mean	Maximum	Minimum	Maximum	Minimum			
	° F.	° F.	° F.	° F.	° F.	*Miles*	*Inches*	*Inches*
1919:								
April	43	54	32	75	24	7.4	1.72	3.74
May	56	69	43	93	20	7.0	3.95	6.02
June	69	83	56	102	32	6.4	1.12	7.26
July	74	89	59	100	47	5.4	.85	9.17
August	71	87	55	100	46	5.6	1.22	8.06
September	61	74	47	94	33	6.1	.49	5.35
Average or total	62	76	49	----	----	6.3	9.35	39.60
1920:								
April	35	47	24	60	0	6.7	0.58	3.16
May	56	69	43	88	34	7.9	1.72	5.54
June	66	79	52	93	36	5.7	1.85	6.30
July	71	85	58	103	50	4.6	2.68	7.16
August	71	86	55	100	39	5.3	1.81	8.45
September	60	73	46	93	25	4.4	1.29	4.65
Average or total	60	73	46	----	----	5.8	9.93	35.26
1921:								
April	43	56	30	83	14	6.3	2.59	3.64
May	55	67	43	89	27	6.3	3.05	5.15
June	71	84	58	108	41	5.6	.82	7.32
July	74	89	59	110	52	4.7	3.38	8.90
August	71	86	56	102	43	5.4	.25	8.52
September	59	73	46	95	31	7.1	1.58	5.73
Average or total	62	76	49	----	----	5.9	11.67	39.26
1922:								
April	45	56	33	89	15	6.4	0.66	3.38
May	58	70	46	81	36	7.2	2.05	5.34
June	66	78	54	96	45	4.3	3.43	5.64
July	68	82	55	96	38	3.8	3.17	6.74
August	73	87	58	101	49	4.7	.32	7.94
September	61	75	48	98	33	4.5	2.31	4.83
Average or total	62	75	49	----	----	5.2	11.94	33.87

WATER REQUIREMENT OF CROP PLANTS

WHEAT

Kubanka wheat (*Triticum durum*) was grown during the four seasons 1919 to 1922. The detailed results are shown in Table 21.

The water requirement of wheat was low in two years—340±4 in 1920 and 372±8 in 1922—and high in 1919 (520±11) and in 1921 (351±8). The high values in 1919 and 1921 are correlated with high evaporation during the months of June and July in those years as compared with the same months in 1920 and 1922. (Table 20.) The close correlation between evaporation and water requirement of Kubanka wheat is shown graphically in Figure 10. A view of some of the plants grown in 1922 is shown in Figure 6.

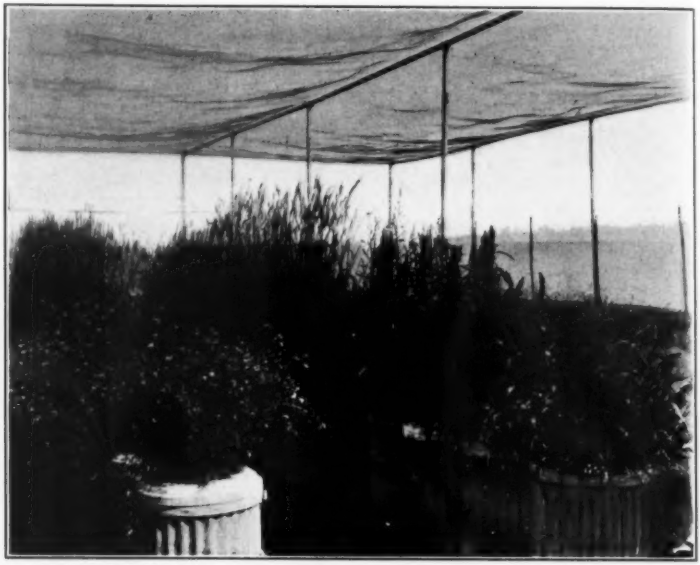

FIGURE 6.—Baltic alfalfa (left foreground), varieties of wheat (background), and weeds (right foreground), in the water-requirement experiments at Mandan, N. Dak., July 26, 1922

TABLE 20.—*Evaporation by 5-day periods from April to September, inclusive, 1919–1922, at Mandan, N. Dak.*

Period (dates inclusive)	Seasonal evaporation for—			
	1919	1920	1921	1922
	Inches	*Inches*	*Inches*	*Inches*
April:				
1–5	0.409	0.351	0.772	0.309
6–10	.418	.502	.146	.363
11–15	.378	.594	.771	.437
16–20	.899	.524	.890	.455
21–25	.852	.380	.397	.913
26–30	.783	.804	.672	.902
Total	3.739	3.155	3.638	3.379
May:				
1–5	0.531	0.181	1.051	0.899
6–10	.568	.833	.722	.621
11–15	.978	1.181	.762	.662
16–20	.792	1.027	.837	.958
21–25	1.174	1.144	1.036	1.104
26–31	1.979	1.177	.739	1.093
Total	6.022	5.543	5.147	5.337
June:				
1–5	0.993	0.830	0.873	1.344
6–10	.925	1.168	.786	.634
11–15	1.136	1.135	1.130	.745
16–20	1.229	1.335	1.411	.875
21–25	1.252	1.034	1.461	1.056
26–30	1.723	.795	1.663	.984
Total	7.258	6.297	7.324	5.638

Period (dates inclusive)	Seasonal evaporation for—			
	1919	1920	1921	1922
	Inches	*Inches*	*Inches*	*Inches*
July:				
1–5	1.431	1.031	1.501	1.235
6–10	1.821	1.017	1.702	1.043
11–15	1.398	1.013	1.308	1.125
16–20	1.783	1.069	1.234	1.114
21–25	1.301	1.452	1.807	1.076
26–31	1.434	1.575	1.347	1.147
Total	9.168	7.157	8.899	6.740
August:				
1–5	1.257	1.167	1.420	1.200
6–10	1.293	1.421	1.305	1.096
11–15	1.370	1.116	1.223	1.683
16–20	1.610	1.867	1.368	1.455
21–25	1.087	1.505	1.409	1.395
26–31	1.440	1.376	1.799	1.106
Total	8.057	8.452	8.524	7.935
September:				
1–5	0.870	0.438	1.551	0.989
6–10	.909	.695	.916	1.171
11–15	1.095	1.238	.250	.396
16–20	1.106	.846	.878	.592
21–25	.944	.722	1.019	.777
26–30	.423	.708	1.116	.901
Total	5.347	4.647	5.730	4.826
Total for season	39.591	35.251	39.262	33.855

TABLE 21.—*Water requirement of Kubanka wheat (C. I. 1440), 1919–1922, at Mandan, N. Dak.*

Year and period of growth	Pot No.	Dry matter	Grain		Water	Water requirement based on—	
						Grain	Dry matter
		Grams	*Grams*	*Per cent*	*Kgm.*		
1919: May 16 to Aug. 6 (81 days)	1	111.2	33.0	30	58.5	1,773	526
	2	91.7	17.5	19	44.5	2,543	485
	3	104.4	32.2	31	50.8	1,578	487
	4	127.3	24.1	19	64.2	2,664	504
	5	116.8	20.3	17	63.1	3,108	540
	6	130.1	25.4	20	75.1	2,957	577
Mean		113.6	25.4			2,437±192	520±11
1920: May 19 to Aug. 18 (78 days)	1	153.0	50.0	33	48.3	966	316
	2	145.2	40.2	28	48.6	1,208	335
	3	142.0	42.0	30	50.3	1,198	354
	4	153.4	52.7	34	51.8	983	338
	5	149.0	54.0	36	51.4	952	345
	6	145.7	51.5	35	51.5	1,000	353
Mean		148.1	48.4			1,051±38	340±4
1921: May 18 to July 31 (75 days)	1	94.0	(a)		52.8		562
	2	133.0			70.3		528
	3	113.5			62.3		549
	4	110.4			56.7		514
	5	115.0			57.6		501
Mean		113.2					531±8
1922: May 16 to Aug. 14 (90 days)	1	258.7	94.0	36	104.3	1,110	403
	2	202.1	76.7	38	73.4	957	363
	3	194.0	72.1	37	75.0	1,040	387
	4	218.4	84.3	39	74.0	878	339
	5	199.7	75.4	38	73.9	980	370
Mean		214.6	80.5			991±18	372±8

[a] Unfortunately some loss of grain, due to damage by birds, occurred a day or two before harvesting the plants in 1921. The yield of dry matter, therefore, should have been somewhat greater than that actually obtained, and the water requirement somewhat lower than indicated. Probably the true value was between 500 and 520.

In 1922 four distinct types of wheat were grown in order to determine their relative economy in the use of water. The varieties were Kubanka, Marquis, Kota, and Hard Federation. They were grown in pots of soil which had been planted to flax the previous year. The results are shown in Table 22. The yield of grain and of total dry matter was satisfactory and much the same in the four varieties. Kubanka gave the lowest value, 311 ± 4, based on total dry matter, followed by Marquis, 355 ± 7; Kota, 393 ± 6; and Hard Federation, 405 ± 4. The water requirement of the four varieties, based on grain, showed a similar variation, ranging from 847 ± 11 for Kubanka to $1{,}124 \pm 20$ for Hard Federation. The yields in field plots varied in the same order as the water requirement, except for the Marquis variety, which was fourth in yield. The yields of grain in replicated field plots in bushels per acre were as follows: Kubanka, 19.6; Kota, 18.6; Hard Federation, 18.1; and Marquis, 16.7.

TABLE 22.—*Water requirement in 1922 of four varieties of wheat grown in pots of soil which had been planted to flax the previous year (1921), at Mandan, N. Dak.*

Plant and period of growth	Pot No.	Dry matter	Grain		Water	Water requirement based on—	
						Grain	Dry matter
TRITICUM DURUM							
Kubanka, C. I. 1440, May 27 to Aug. 8 (86 days)		*Grams*	*Grams*	*Per cent*	*Kgm.*		
	6	148.5	53.3	36	45.8	859	308
	7	142.3	55.7	39	42.6	765	299
	8	208.7	71.6	34	68.3	954	327
	9	161.3	62.3	39	48.7	781	302
	10	181.3	65.7	36	57.7	878	318
Mean		168.4	61.7			847±11	311±4
T. VULGARE							
Hard Federation C. I. 4733, May 27 to Aug. 16 (81 days)	11	153.9	56.7	37	63.5	1,120	413
	12	181.2	66.6	37	74.0	1,111	408
	13	156.4	59.8	38	62.8	1,050	402
	14	142.5	50.0	35	54.7	1,094	384
	15	150.6	50.8	34	63.1	1,242	419
Mean		156.9	56.8			1,124±20	405±4
Kota, C. I. 5878, May 27 to Aug. 18 (83 days)	16	180.6	68.7	38	70.0	1,019	388
	17	198.8	75.6	38	75.4	997	379
	18	157.4	58.6	37	63.7	1,087	405
	19	159.2	62.1	39	59.2	953	372
	20	186.8	68.9	37	78.2	1,135	419
Mean		176.6	66.8			1,038±25	393±6
Marquis, C. I. 3641, May 27 to Aug. 16 (81 days)	21	156.5	61.1	39	54.9	899	351
	22	162.9	62.2	38	59.7	960	366
	23	163.0	58.5	37	63.3	1,082	388
	24	154.5	60.0	39	51.7	862	335
	25	164.5	65.4	40	55.0	841	334
Mean		160.3	61.4			929±31	355±7

MILLET

Kursk millet, A. D. I. 3 (*Chaetochloa italica*), was grown in 1919 and 1920. (Table 23.) Its water requirement based on dry matter was 303 ± 2 in 1919 and 186 ± 1 in 1920. The value based on grain in 1919 was 1,337 ± 40. In 1920 the millet was harvested before the seed was fully mature, and the water requirement based on grain was not determined.

TABLE 23.—*Water requirement of Kursk millet (A. D. I. 3) in 1919 and 1920, at Mandan, N. Dak.*

Period of growth	Pot No.	Dry matter	Grain		Water	Water requirement based on—	
						Grain	Dry matter
		Grams	*Grams*	*Per cent*	*Kgm.*		
1919: June 15 to Aug. 21 (67 days)	31	258.2	62.0	24	78.0	1,259	302
	32	252.2	53.1	21	77.5	1,460	307
	33	245.7	54.2	22	74.0	1,365	301
	34	243.8	50.0	21	75.3	1,506	309
	35	254.2	63.1	25	75.9	1,203	299
	36	281.2	66.8	24	82.0	1,228	292
Mean		255.9	58.2			1,337±40	303±2
1920: June 15 to July 31 (64 days)	7	198.0			36.9		186
	8	229.8			41.3		180
	9	213.5			39.7		186
	10	201.0			38.1		189
	11	216.8			39.1		180
	12	194.5			37.8		194
Mean		208.9					186±1

Sorgo and Sudan Grass

Dakota Amber sorgo (*Sorghum vulgare*) and Sudan grass (*S. vulgare* var. *sudanense*) were grown in 1919 and 1920. In 1920 an F_3 hybrid of those varieties also was grown. The results are shown in Table 24.

As in the results with wheat and millet, a higher water requirement was recorded in 1919 than in 1920. The average water requirement of Sudan grass (311 ± 4) for the 2-year period was 24 per cent higher than that of Dakota Amber sorgo (251 ± 2). The hybrid (224 ± 1) gave approximately the same value as sorgo in 1920.

Table 24.—*Water requirement of Dakota Amber sorgo and Sudan grass in 1919 and 1920, and of an F_3 hybrid of Dakota Amber sorgo×Sudan grass in 1920, at Mandan, N. Dak.*

Plant and period of growth	Pot No.	Dry matter	Grain		Water	Water requirement based on—	
						Grain	Dry matter
DAKOTA AMBER SORGO							
		Grams	*Grams*	*Per cent*	*Kgm.*		
1919: June 15 to Aug. 21 (67 days)	25	285.8	107.2	38	77.2	720	270
	26	263.0	106.0	40	72.4	683	275
	27	250.0	98.1	39	69.1	704	276
	28	279.2	101.2	36	75.4	745	270
	29	229.4	65.8	29	63.3	*962	276
	30	260.1	99.0	38	70.1	708	270
Mean		261.3	96.2			712±5	273±1
1920: June 15 to Aug. 18 (64 days)	25	184.7			41.6		225
	26	173.7			40.8		235
	27	186.0			41.1		221
	28	178.0			40.9		230
	29	173.8			41.2		237
	30	168.8			38.2		226
Mean		177.5					229±2
SUDAN GRASS							
1919: June 15 to Aug. 21 (67 days)	37	204.2			71.2		349
	38	232.4			77.4		333
	39	220.1			75.1		341
	40	231.2			78.1		338
	41	217.7			78.5		361
	42	226.2			80.9		358
Mean		222.0					347±4
1920: June 25 to Aug. 18 (64 days)	13	202.7			55.8		275
	14	219.8			56.9		259
	15	193.1			55.7		288
	16	203.6			57.1		280
	17	211.3			56.7		268
	18	207.8			56.7		273
Mean		206.4					274±3
DAKOTA AMBER SORGO×SUDAN GRASS, F_3							
1920: June 15 to Aug. 18 (64 days)	37	152.5			34.1		224
	38	157.9			34.9		221
	39	148.0			33.4		226
	40	161.7			36.2		224
	41	156.3			34.6		221
	42	156.7			35.2		225
Mean		155.5					224±1

* Not included in the mean.

Alfalfa

In the experiments at Mandan less attention was given than at Newell to the comparative water requirement of different varieties of alfalfa. Instead of determining the water requirement of many varieties, an effort was made to determine the effect of time of cutting, that is, the period of growth, on the water requirement of alfalfa. This subject is discussed under the heading "Effect of Cutting Alfalfa at Different Stages of Growth" on page 2.

The water requirement of Grimm, A. D. I. E–23, as grown to maturity for seed in 1921, and that of Baltic, A. D. I. H–4–58, cut twice in 1922, are shown in Table 25.

Table. 25.—*Water requirement of Grimm alfalfa (A. D. I. E–23), grown to maturity for seed in 1921, and of Baltic alfalfa (A. D. I. H–4–58), cut in early-bloom stage, in 1922, at Mandan, N. Dak.*

Plant and period of growth	Pot. No.	Dry matter	Water	Water requirement based on dry matter
GRIMM, A. D. I. E–23				
		Grams	*Kgm.*	
1921: June 9 to Sept. 2 (85 days)	26	94.0	94.2	1,002
	27	90.0	95.0	1,055
	28	102.0	96.6	947
	29	100.5	82.2	818
	30	105.4	90.3	857
Mean		98.4		936±33
BALTIC, A. D. I. H–4–58				
1922: Midsummer June 1 to July 26 (55 days)	26	50.1	36.9	737
	27	50.4	39.8	790
	28	68.4	52.8	772
	29	80.2	61.2	763
	30	47.7	42.9	899
Mean		59.4		792±18
Late summer, July 26 to Sept. 1 (37 days)	26	55.3	41.1	743
	27	64.7	41.4	640
	28	80.5	58.6	728
	29	95.0	64.4	678
	30	65.0	47.0	723
Mean		72.1		702±15
Combined crop, June 1 to Sept. 1 (92 days)	26	105.4	78.0	740
	27	115.1	81.2	705
	28	148.9	111.4	748
	29	175.2	125.6	717
	30	112.7	89.9	798
Mean		131.5		742±11

Flax

Four varieties of flax (*Linum usitatissimum*)were grown in 1921 and six varieties in 1922 in order to determine the water requirement of this crop as grown for seed production (linseed). The data are shown in Table 26.

TABLE 26.—*Water requirement of varieties of seed flax in 1921 and 1922, at Mandan, N. Dak.*

Plant and period of growth	Pot No.	Dry matter	Seed		Water	Water requirement based on—	
						Seed	Dry matter
DAMONT, C. I. 3		*Grams*	*Grams*	*Per cent*	*Kgm.*		
1921: June 9 to Sept. 2 (85 days)	6	114.8	34.5	30	89.4	2,590	778
	7	107.2	28.3	26	81.3	2,870	758
	8	87.5	28.1	32	78.1	2,780	892
	9	112.7	36.0	32	97.2	2,700	862
	10	111.8	36.8	33	90.4	2,457	808
Mean		106.8	32.7			2,679±53	820±19
1922: June 13 to Oct. 5 (114 days)	51	85.6	30.4	36	75.6	2,487	883
	52	78.8	27.3	35	71.1	2,604	902
	53	58.0	19.3	33	46.4	2,404	800
	54	56.1	20.2	36	52.8	2,614	941
	55	78.0	26.7	34	67.1	2,513	860
Mean		71.3	24.8			2,524±29	877±11
RESERVE C. I. 19							
1921: June 9 to Sept. 2 (85 days)	21	104.3	34.0	33	86.3	2,540	826
	22	101.1	33.8	33	89.2	2,639	882
	23	113.5	34.1	30	90.7	2,660	800
	24	111.4	34.2	31	90.4	2,643	812
	25	117.5	35.1	30	90.5	2,580	770
Mean		109.6	34.2			2,612±18	818±12
1922: June 13 to Oct. 5 (114 days)	56	86.3	28.1	33	78.0	2,776	904
	57	75.1	25.1	33	65.3	2,602	870
	58	72.9	23.8	33	64.5	2,710	885
	59	85.7	28.8	34	69.6	2,417	812
	60	82.3	28.6	35	65.7	2,297	798
Mean		80.4	26.9			2,560±69	854±16
PRIMOST, C. I. 12							
1921: June 9 to Aug. 22 (74 days)	11	86.3	22.6	26	65.3	2,890	757
	12	91.1	25.0	27	69.1	2,765	759
	13	87.0	23.4	27	64.6	2,760	743
	14	90.0	23.5	26	67.5	2,870	750
	15	88.0	24.5	28	64.2	2,620	730
Mean		88.5	23.8			2,781±33	748±4
1922: June 13 to Oct. 5 (114 days)	76	76.5	25.8	34	57.7	2,236	754
	77	84.2	30.5	36	70.5	2,311	837
	78	80.2	27.5	34	64.4	2,342	803
	79	67.5	21.9	32	54.1	2,470	801
	80	81.5	28.7	35	65.9	2,296	808
Mean		78.0	26.9			2,331±26	801±8
NORTH DAKOTA RESISTANT NO. 114, C. I. 13							
1921: June 9 to Aug. 22 (74 days)	16	79.0	18.3	23	62.4	3,410	790
	17	82.6	19.3	23	60.7	3,145	735
	18	81.5	19.7	24	60.6	3,075	744
	19	76.7	18.2	24	58.3	3,203	760
	20	74.5	19.7	26	56.0	2,845	752
Mean		78.9	19.0			3,135±59	756±6
1922: June 13 to Oct. 5 (114 days)	71	77.7	24.5	32	51.4	2,098	662
	72	71.2	26.1	37	54.3	2,080	763
	73	69.7	27.1	39	55.5	2,048	796
	74	57.2	20.1	35	40.7	2,025	712
	75	58.2	20.5	35	43.1	2,102	741
Mean		66.8	23.7			2,070±11	735±12

TABLE 26.—*Water requirement of varieties of seed flax in 1921 and 1922, at Mandan, N. Dak.*—Continued

Plant and period of growth	Pot No.	Dry matter	Seed		Water	Water requirement based on—	
						Seed	Dry matter
WINONA, C. I. 179		*Grams*	*Grams*	*Per cent*	*Kgm.*		
1922: June 13 to Oct. 5 (114 days)	66	64.5	25.0	39	44.6	1,784	691
	67	68.7	26.6	39	50.5	1,898	736
	68	61.3	20.5	33	45.5	2,219	742
	69	72.9	27.8	38	57.3	2,061	786
	70	69.0	23.7	34	50.7	2,139	735
Mean		67.3	24.7			2,020±61	738±9
LETHBRIDGE GOLDEN, C. I. 23							
1922: June 13 to Oct. 5 (114 days)	61	67.5	26.0	39	62.8	2,415	930
	62	73.1	26.0	36	64.8	2,492	886
	63	65.3	23.3	36	58.5	2,511	896
	64	72.0	27.5	38	64.8	2,356	900
	65	74.1	27.0	36	66.7	2,470	900
Mean		70.4	26.0			2,449±18	902±5

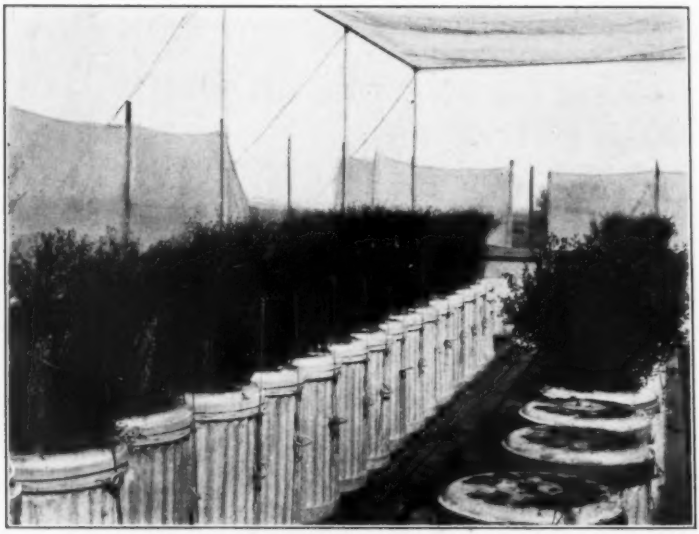

FIGURE 7.—Flax varieties (at left) and Grimm alfalfa grown in the water-requirement experiments at Mandan, N. Dak. Photographed August 22, 1921

The two varieties Damont and Reserve are of similar type—the so-called Russian or European blue-flowered seed flaxes, which formerly were grown extensively on new lands in the Dakotas and Montana. The three varieties N. D. R.[7] 114, Primost, and Winona are small seeded and more or less wilt resistant. Lethbridge Golden is not grown commercially. It has large chamois-yellow seeds and pale-pink flowers. (Fig. 7.)

[7] North Dakota Resistant.

Based on dry matter, the varieties Primost and N. D. R. 114 had a somewhat lower water requirement than Damont and Reserve, the values ranging from 746 for N. D. R. 114 to 848 for Damont. Based on seed production, their water requirements were very similar, ranging from 2,556 for Primost to 2,602 for N. D. R. 114.

The yield of flaxseed in these pot experiments was satisfactory and apparently quite normal, the calculated yields per acre ranging from about 12 to 22 bushels.

FIGURE 8.—Some common weeds (witch grass, redroot pigweed, lamb's-quarters, and Russian thistle) grown in the water-requirement experiments at Mandan, N. Dak.

WATER REQUIREMENT OF WEEDS

In 1919 and in 1922 a few common weeds were grown in the water-requirement experiments. The data are shown in Table 27.

Although the experiments were few, the results indicate that Russian thistle (*Salsola tenuifolia*), redroot pigweed (*Amaranthus retroflexus*), and witch grass (*Panicum capillare*) are highly efficient in the use of water. A photograph of redroot pigweed and lamb's-quarters (*Chenopodium album*) taken on the day the plants were cut, July 26, 1922, is shown in Figure 8.

TABLE 27.—*Water requirement of five common weeds in 1919 and 1922 at Mandan, N. Dak.*

Plant and period of growth	Pot No.	Dry matter	Water	Water requirement based on dry matter
		Grams	*Kgm.*	
RUSSIAN THISTLE (SALSOLA TENUIFOLIA)				
1919: June 15 to July 16 (31 days)	43	118.0	25.9	218
	44	102.6	26.0	253
	45	112.1	26.7	238
Mean		110.9		237±7
July 31 to Sept. 11 (42 days)	45	44.3	11.8	266
1922: June 12 to July 26 (44 days)	85	227.2	45.4	200
	86	228.5	47.6	208
Mean		227.9		204±3
REDROOT PIGWEED (AMARANTHUS RETROFLEXUS)				
1919: June 15 to July 16 (31 days)	46	78.5	18.8	240
	47	59.4	16.9	284
	48	53.2	15.5	291
Mean		63.7		272±12
1922: June 12 to July 26 (44 days)	83	202.1	48.9	242
WITCH GRASS (PANICUM CAPILLARE)				
1919: July 31 to Sept. 15 (46 days)	43	11.6	3.5	302
	44	25.0	6.6	264
Mean		18.3		283±16
1922: June 12 to July 26 (44 days)	81	186.6	41.8	224
	82	137.7	30.0	218
Mean		162.2		221±3
PURSLANE (PORTULACA OLERACEA)				
1919: July 28 to Sept. 11 (45 days)	46	20.7	6.7	324
	47	24.3	7.2	296
	48	28.5	9.4	330
Mean		24.5		317±8
LAMB'S-QUARTERS (CHENOPODIUM ALBUM)				
1922: June 6 to July 26 (44 days)	84	214.1	82.0	383

EFFECT OF CUTTING ALFALFA AT DIFFERENT STAGES OF GROWTH

In experiments at Akron, Colo., in 1912, Briggs and Shantz (*2*) found that when alfalfa was clipped at weekly intervals the water requirement was somewhat higher (975 ± 23) than when it was cut in the usual manner, that is, in the early-blossom stage for hay (853 ± 13). The total yield of dry matter was much less in the series frequently clipped than in the series cut for hay, the yields being 27 and 128 gm. per pot, respectively. The growth period covered 42 days, from July 26 to September 6, the one series being clipped six times, the other only once.

In 1919 the writer carried on a similar but more extensive experiment at Mandan, N. Dak. Three sets of pots of Grimm alfalfa, A. D. I. E–23, were grown in order to determine the water requirement of alfalfa under three conditions of cutting: (1) When the plants are allowed to mature seed; (2) when the plants are cut in the early blossom stage, as for hay; and (3) when the plants are clipped at intervals of two weeks, simulating pasture conditions. A duplicate experiment was conducted with yellow-flowered alfalfa, *Medicago falcata*.

The water requirement of Grimm alfalfa, A. D. I. E–23, when harvested in the three stages of growth described above, is shown in Table 28.

TABLE 28.—*Water requirement of Grimm alfalfa (A. D. I. E–23), in 1919, at Mandan, N. Dak.: (A) When matured for seed; (B) when cut in early bloom for hay; and (C) when cut at intervals of two weeks, to imitate pasturing*

Series A.—Matured for seed					Series B.—Harvested in early-bloom stage					Series C.—Cropped at intervals				
Period of growth	Pot No.	Dry matter	Water absorbed	Water requirement	Period of growth	Pot No.	Dry matter	Water absorbed	Water requirement	Period of growth	Pot No.	Dry matter	Water absorbed	Water requirement
		Grams	*Kgm.*				*Grams*	*Kgm.*				*Grams*	*Kgm.*	
					Early summer, June 15 to July 19 (34 days).	55	30.0	22.7	757	Early summer, June 15 to July 19 (34 days).	61	21.6	16.7	773
						56	34.2	24.3	711		62	35.3	24.9	705
						57	33.2	24.4	735		63	32.2	25.1	780
						58	28.4	21.4	754		64	29.7	22.9	771
						59	32.6	26.9	825		65	36.9	27.8	753
						60	40.2	28.0	697		66	35.5	24.9	702
					Mean		33.1		747±12	Mean		31.9		747±11
Early midsummer and June 15 to Aug. 22 (68 days).	49	104.5	94.0	900	Midsummer, July 19 to Aug. 22 (34 days).	55	53.7	39.7	739	Midsummer, July 19 to Aug. 22 cropped Aug. 2, 16, and 22.	61	36.0	19.8	550
	50	103.3	94.5	915		56	60.5	43.1	712		62	53.3	33.4	627
	51	102.4	88.2	861		57	48.4	32.9	680		63	51.4	32.8	638
	52	84.6	87.3	1,032		58	62.5	47.0	752		64	56.9	36.6	643
	53	93.9	93.7	998		59	50.4	36.9	732		65	45.0	30.1	669
	54	89.3	79.2	887		60	61.0	42.9	703		66	45.8	31.6	690
Mean		96.3		932±21	Mean		56.1		720±8	Mean		48.1		636±11
Late summer, Aug. 22 to Oct. 7 (46 days).	49	59.6	44.3	743	Late summer, Aug. 22 to Oct. 7 (46 days).	55	50.7	35.9	708	Late summer, Aug. 22 to Oct. 7 cropped Sept. 15 and Oct. 7.	61	33.4	17.6	527
	50	60.8	43.3	712		56	55.7	36.4	654		62	42.9	23.0	536
	51	57.8	44.5	770		57	47.2	30.6	648		63	39.6	21.8	551
	52	50.6	41.5	820		58	61.5	38.8	631		64	33.8	23.5	695
	53	57.0	41.6	730		59	48.6	33.8	695		65	40.8	22.1	542
	54	45.7	32.6	713		60	49.2	32.8	667		66	42.3	23.8	563
Mean		55.3		748±12	Mean		52.2		667±9	Mean		38.8		569±10
Combined crop, June 15 to Oct. 7 (114 days).	49	164.1	138.3	843	Combined crop, June 15 to Oct. 7 (114 days).	55	134.4	98.3	731	Combined crop, June 15 to Oct. 7 (114 days).	61	91.0	54.1	595
	50	164.1	137.8	840		56	150.4	103.8	690		62	131.5	81.3	618
	51	160.2	132.7	828		57	128.8	87.9	682		63	123.2	79.7	647
	52	135.2	128.8	952		58	152.4	107.2	703		64	120.4	83.0	689
	53	150.9	135.3	897		59	131.6	97.6	742		65	122.7	80.0	652
	54	135.0	111.8	828		60	150.4	103.7	689		66	123.6	80.3	650
Mean		151.6		865±15	Mean		141.3		706±8	Mean		118.7		642±9

The water requirement of the seed-producing crop (series A, Table 28) grown during the period June 15 to August 22 was 932 ± 21 as compared with 730 ± 10 for the two crops cut in the early bloom stage (series B) and covering exactly the same period of growth. Nearly the same difference was obtained with the yellow-flowered alfalfa *(Medicago falcata)* shown in Table 29. The water requirement of the seed crop of *M. falcata* (series A), covering the period June 20 to August 22, was 884 ± 19, as compared with 731 ± 10, the combined value of the two crops cut in the early-bloom stage and covering the same period of growth.

The seed crop of Grimm alfalfa required 28 per cent more water to produce a unit quantity of dry matter than did the combined crops grown during the same period and cut in the proper stage for hay. The seed crop of *Medicago falcata* required 21 per cent more water than the combined hay crop to produce a unit quantity of dry matter.

In 1921, Grimm alfalfa, A. D. I. E–23, grown to maturity for seed, had a water requirement of 936 ± 33. (See Table 25.)

In an earlier experiment at Newell, S. Dak., in 1918, Grimm alfalfa, A. D. I. E–23, grown for seed, had a water requirement of $1,399 \pm 14$, as compared with the combined value 955 ± 10 of two crops cut in early bloom. (See Table 13.) The growth period covered 99 days—June 25 to October 2—in both cases. In this experiment the seed crop required 46 per cent more water to produce a unit quantity of dry matter than did the combined crops cut in the proper stage of growth for hay.

In series B and series C (Table 28) the first or early-summer crop was grown to the early-bloom stage, and both sets had exactly the same water requirement, 747 ± 12. During the second period, midsummer, series B was cut only once, on August 22 at the end of the 34-day period, while series C was cropped three times, on August 2, 16, and 22. The water requirement of series B was 720 ± 8 as compared with 636 ± 11 for series C.

In the late summer, August 22 to October 7, series B, cut once, had a water requirement of 667 ± 9, as compared with 569 ± 10 in series C, which was cropped twice, on September 15 and October 7.

In yield of dry matter, the two series produced approximately the same quantity during the first or early-summer period—33.1 gm. per pot in series B and 31. 9 gm. in series C. This indicates that the two series were of equal vigor at the beginning of the experiment. In the midsummer period, series B yielded 56.1 gm. per pot, as compared with 48.1 gm. in series C. In the late-summer period, series B yielded 52.2 gm. per pot, as compared with 38.8 gm. in series C. The yield of series C, therefore, was 86 per cent of that of series B during the midsummer period and 74 per cent of series B during the late-summer period. The reduced leaf area of the plants, brought about through frequent cutting, reduced the total quantity of water transpired and also the quantity of dry matter produced by the plant.

The experiment with the yellow-flowered alfalfa (Table 29) was not so satisfactory, because of the slow seedling growth of this species and its slow recovery after cutting. The water requirement of series B—cut in early-bloom stage—was approximately the same as that of series C, which was cropped at more frequent intervals. The values for the midsummer period were 717 ± 14 for series B and 727 ± 13 for series C. In the late-summer period the values were 734 ± 20 and 753 ± 18, respectively. The differences in either period are not significant.

TABLE 29.—*Water requirement of yellow-flowered alfalfa in 1919, at Mandan N. Dak.: (A) When matured for seed (B) when cut in early bloom for hay; and (C) when cut at intervals of two weeks, to imitate pasturing*

Series A.—Matured for seed					Series B.—Harvested in early-bloom stage					Series C.—Cropped at intervals of two weeks				
Period of growth	Pot No.	Dry matter	Water absorbed	Water requirement	Period of growth	Pot No.	Dry matter	Water absorbed	Water requirement	Period of growth	Pot No.	Dry matter	Water absorbed	Water requirement
		Grams	*Kgm.*				*Grams*	*Kgm.*				*Grams*	*Kgm.*	
					Early summer, June 20 to July 19 (29 days).	73	15.7	11.9	758	Early summer, June 20 to July 19 (29 days).	67	8.5	7.7	906
						74	16.0	11.6	725		68	6.3	6.8	1,079
						75	13.2	10.7	811		69	8.5	8.1	953
						76	14.4	11.1	771		70	7.6	7.2	947
						77	37.4	27.0	722		71	8.3	6.6	795
						78	33.8	26.5	784		72	11.5	8.8	765
					Mean		21.8		762±10	Mean		8.5		908±32
Early and midsummer, June 20 to Aug. 22 (63 days).	79	52.9	50.4	753	Midsummer, July 19 to Aug. 22 (34 days).	73	40.2	33.1	824	Midsummer, cropped Aug. 2, 16, and 22 (34 days).	67	24.7	19.0	769
	80	64.6	54.5	844		74	35.8	23.9	688		68	23.9	18.6	778
	81	51.4	44.7	870		75	42.2	30.3	718		69	26.1	19.0	728
	82	58.0	51.0	879		76	53.1	36.4	685		70	23.7	15.7	662
	83	76.7	61.0	795		77	49.7	35.7	718		71	24.6	18.0	732
	84	59.0	56.9	964		78	43.4	29.9	689		72	28.5	19.7	691
Mean		60.4		884±19	Mean		44.1		717±14	Mean		25.3		727±13
Late summer Aug. 22 to Oct. 7 (46 days).	79	22.3	19.8	888	Late summer, Aug. 22 to Oct. 7 (46 days).	73	24.5	20.0	816	Late summer, cropped Sept. 15 and Oct. 7 (46 days).	67	18.5	12.1	654
	80	18.5	18.1	978		74	24.8	18.7	754		68	9.8	7.9	806
	81	14.3	14.1	986		75	27.3	20.3	744		69	13.1	11.1	847
	82	16.2	17.5	1,080		76	36.2	22.0	608		70	10.7	8.5	794
	83	34.5	28.0	812		77	27.6	19.3	699		71	15.4	10.1	656
	84	24.4	23.5	963		78	25.1	19.7	785		72	9.6	7.3	760
Mean		21.7		951±26	Mean		27.6		734±20	Mean		12.8		753±18
Combined crop, June 20 to Oct. 7 (109 days).	79	75.2	70.2	934	Combined crop, June 20 to Oct. 7 (109 days).	73	80.4	65.0	808	Combined crop, June 20 to Oct. 7 (109 days).	67	51.7	38.8	750
	80	83.1	72.6	874		74	76.6	54.2	708		68	40.0	33.3	832
	81	65.7	58.8	895		75	82.7	61.3	741		69	47.7	38.2	800
	82	74.2	68.5	923		76	103.7	69.5	670		70	42.0	31.4	748
	83	111.2	89.0	800		77	114.7	82.0	715		71	48.3	34.7	718
	84	83.4	80.4	964		78	102.3	76.1	744		72	49.6	35.8	722
Mean		82.1		898±16	Mean		93.4		731±13	Mean		46.6		762±14

The high water requirement of the early-summer crop in series C is due to the very low yield of dry matter. The plants, however, were well established and thrifty when the midsummer period began. A summary of the results presented in Tables 28 and 29 is shown in Table 30.

TABLE 30.—*Summary of yield of dry matter and water requirement of Grimm and yellow-flowered alfalfas in 1919 at Mandan, N. Dak., (A) when matured for seed, (B) when cut in early bloom for hay, and (C) when cut at intervals to imitate pasturing*

Plant and period of growth	Dry matter per pot			Water requirement		
	Series A	Series B	Series C	Series A	Series B	Series C
Grimm, A. D. I. E-23:	*Grams*	*Grams*	*Grams*			
June 15 to July 19		33.1	31.9		747±12	747±11
July 19 to Aug. 22	[a] 96.3	56.1	48.1	[a] 932±21	720±8	636±11
Aug. 22 to Oct. 7	55.3	52.2	38.8	748±12	667±9	569±10
Combined crop, June 15 to Oct. 7	151.6	141.3	118.7	865±15	706±8	642±9
Yellow-flowered alfalfa:						
June 20 to July 19		21.8	8.5		762±10	908±32
July 19 to Aug. 22	[b] 60.4	44.1	25.3	[b] 884±19	717±14	727±13
Aug. 22 to Oct. 7	21.7	27.6	12.9	951±26	734±20	753±18
Combined crop, June 20 to Oct. 7	82.1	93.4	46.6	898±16	731±13	762±14

[a] For the period June 15 to Aug. 22 [b] For the period June 20 to Aug. 22.

EFFECT OF ENFORCED DROUGHT ON WATER REQUIREMENT AND YIELD OF OATS

It is a common observation that if drought occurs during the normally rapid growth period of a crop the yield of the crop is liable to be greatly reduced. It is of interest to know what effect enforced drought has on the water requirement. Does the crop use more or less water in proportion to the dry matter produced? Experiments bearing on this problem were conducted at Newell, S. Dak., in 1918 and at Mandan, N. Dak., in 1919.

Three sets of pots of Swedish Select oats (*Avena sativa*) were grown in a uniform manner except as to the method of watering. In series A (pots 7 to 12) the plants were watered normally—that is, water was added as often as necessary to keep the pots up to the original weight. In series B (pots 13 to 18) the plants were watered normally until the period of heading, when the soil was allowed to dry down until distinct wilting of the leaves occurred at midday on three or four successive days. Water was then added to bring the pots up to the original weight, which was maintained until the plants were ripe. In series C (pots 19 to 24) the plants were allowed to wilt at two periods, first when heading and again during the late milk stage. The data are shown in Table 31.

The most striking effect of the enforced drought was to cut down the yield of total dry matter and of grain. At Newell, 1918, the average yield of dry matter per pot was 120.6 gm. in series A, 80.2 gm. in series B, and 82.5 gm. in series C. At Mandan, 1919, the average yields were 125.8 gm., 102.4 gm., and 89.7 gm., respectively.

TABLE 31.—*Water requirement of Swedish Select oats in 1918 at Newell, S. Dak., and in 1919 at Mandan, N. Dak.: (A) When supplied with water throughout entire growth period, (B) when allowed to wilt severely during heading stage, and (C) when allowed to wilt during heading stage and again when grain was in late milk stage*

Location, year, experiment, and period of growth	Pot No.	Dry matter	Grain	Water	Water requirement based on—	
					Grain	Dry matter
NEWELL, S. DAK., 1918		*Grams*	*Grams*	*Kgm.*		
(A) Water supplied regularly—June 12 to Aug. 14 (63 days).	7	100.9	46.6	39.8	854	394
	8	113.4	55.4	46.1	832	406
	9	117.1	56.7	48.5	856	414
	10	153.3	66.1	66.5	1,007	434
	11	132.3	61.5	56.8	924	429
	12	106.4	38.0	51.7	1,360	486
Mean		120.6	54.1	51.6	972±52	427±9
(B) Plants wilted in heading stage—June 12 to Aug. 14 (63 days).	13	82.0	31.5	36.3	1,152	443
	14	75.8	33.2	31.2	940	411
	15	84.6	30.8	36.0	1,168	426
	16	70.6	26.9	29.3	1,089	415
	17	92.3	45.2	38.7	856	419
	18	75.9	31.8	31.5	991	415
Mean		80.2	33.2	33.8	1,033±39	422±3
(C) Plants wilted in heading and in late milk stages—June 12 to Aug. 10 (59 days).	19	73.1	35.2	24.0	682	329
	20	83.4	40.0	27.1	678	325
	21	81.6	39.1	28.1	719	345
	22	77.8	37.6	25.5	678	328
	23	86.3	41.7	27.3	655	317
	24	92.8	46.3	28.7	620	309
Mean		82.5	40.0	26.8	672±8	326±3
MANDAN, N. DAK., 1919						
(A) Water supplied regularly—June 2 to Aug. 5 (64 days).	7	123.4	32.4	91.1	2,812	738
	8	123.7	37.6	82.7	2,199	669
	9	122.0	28.0	86.5	3,089	709
	10	123.3	31.1	90.9	2,923	737
	11	132.2	36.5	94.5	2,589	715
	12	130.4	37.5	89.4	2,384	686
Mean		125.8	33.9	89.2	2,666±104	709±8
(B) Plants wilted in heading stage—June 2 to Aug. 2 (61 days)	13	104.8	19.2	73.8	3,844	704
	14	100.0	15.6	70.8	4,538	708
	15	101.1	20.2	70.2	3,475	694
	16	102.8	19.7	70.4	3,574	685
	17	100.3	18.2	71.3	3,918	711
	18	105.1	19.0	72.3	3,805	688
Mean		102.4	18.7	71.5	3,859±93	698±5
(C) Plants wilted in heading and in late milk stages—June 2 to Aug. 2 (61 days).	19	86.4	20.2	57.3	2,837	663
	20	85.3	14.5	63.3	4,365	742
	21	81.5	19.1	60.8	3,183	746
	22	95.1	27.3	62.2	2,278	654
	23	94.8	30.0	61.7	2,057	651
	24	95.1	29.7	61.8	2,081	650
Mean		89.7	23.5	61.2	2,800±185	684±15

The water requirement, based on dry matter, was practically the same in series A and B, but significantly lower in series C, at Newell in 1918. The values were 427 ± 9, 422 ± 3, and 326 ± 3, respectively. At Mandan in 1919 the water requirement of the three series was the

same, within the range of experimental error. Because of a less favorable season, however, the values were higher than in 1918. The water requirement in series A was 709 ± 8; series B, 698 ± 5; and series C, 684 ± 15.

The water requirement based on grain ranged from 672 ± 8 to 1,033 ± 39 in 1918 and from 2,666 ± 104 to 3,859 ± 93 in 1919.

It will be seen (Table 31) that the yield of grain in series B, where the plants were allowed to wilt only at heading time, was less than in series C, where wilting occurred at two critical periods—the heading and milk stages. This apparent inconsistency can be explained by the observation that in series B the plants began a secondary growth of tillers, when water was supplied, after wilting in the heading stage, whereas, in series C the second period of soil drought had a tendency to limit the vegetative growth and to force maturity of the plants. This resulted in a higher yield of grain in series C than in series B.

The effect of enforced soil drought on the daily rate of transpiration is striking. The plants in series B, which transpired 0.56 inch of water per day during the period July 6 to 10, reduced transpiration to 0.22 inch during the period July 11 to 16. The mean daily transpiration of series C was reduced from 0.57 inch (July 6 to 10) to 0.28 inch during the first period of wilting (July 11 to 15) and to 0.17 inch during the second period (July 21 to 25).

In Figure 9 the mean daily transpiration by 5-day periods of each series in comparison with evaporation from a free water surface is shown. At the base of the graph is shown also the quantity of water added and the date of watering. In series A a high rate of transpiration was maintained for a period of about 20 days from July 5 to 25. In series B the rate of transpiration was only partly regained after the period of enforced drought, July 10 to 15, whereas in series C transpiration continued at a low rate after July 10 because of the two periods of enforced drought. The graph indicates quite clearly the reaction of crop plants to the soil-moisture supply.

The injurious effects of soil drought on the transpiration, growth, and yield of oats were evident from the facts that (1) when water was supplied after a period of wilting, transpiration continued at a low rate for three or four days; (2) the normal rate of transpiration was never regained, because of the reduced leaf area; (3) the vegetative growth of the plants was checked; and (4) the yield of dry matter and of grain was reduced. On the other hand, soil drought did not have a significant effect on the water requirement except in one case (series C, 1918) when the two periods of soil drought apparently lowered the water requirement as compared with series A and B. In this case there appears to have been some real adaptation of the plants to conditions of drought. This is in agreement with the results reported by Maksimov (*8*)—that a single period of wilting of the sunflower decreased the yield of dry matter to 40 per cent of the check, whereas subsequent wilting did not cause any further significant injury to the plants.

EFFECT OF SEASON ON WATER REQUIREMENT

Two significant results have been obtained in nearly all investigations of the use of water by crop plants: (1) Crop plants of different species show a marked difference in their efficiency in the use of water, and (2) seasonal conditions have a marked effect on the water require-

ment of a crop. These outstanding results have been confirmed in the experiments conducted by the writer.

In Table 32 the water requirement of alfalfa, wheat, millet, sorgo, and Sudan grass is shown (1) as actual values and (2) as index numbers in comparison with the evaporation from a free water surface during the period of most active crop growth, that is, June to August, inclusive. It is believed that the data obtained at Newell, S. Dak.,

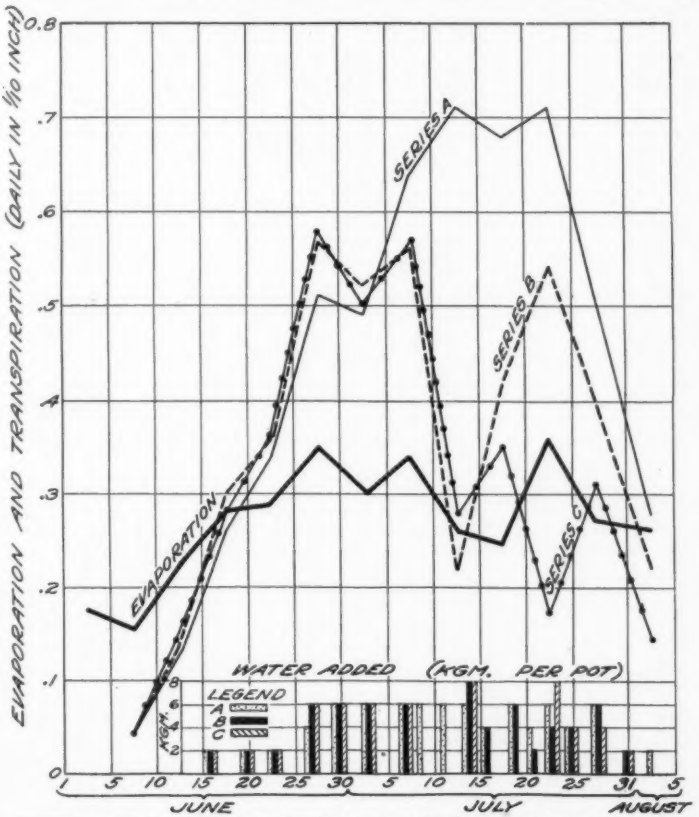

FIGURE 9.—Mean daily transpiration (tenths of an inch based on the soil-surface area of the 16-inch pots) by 5-day periods of Swedish Select oats grown under different conditions of water supply at Mandan, N. Dak., in 1919: Series A, plants watered freely throughout the growing season; B, plants allowed to dry down and wilt on three or four successive days during the heading stage; and C, plants allowed to wilt during the heading stage and again during the late milk stage. Each line represents the mean of six pots, each pot containing from 18 to 20 plants. The heavy line represents the mean daily evaporation from a free water surface. The quantity of water in kilograms added to each pot and the date of watering are shown at the base of the graph. No water was added to series B and C from July 8 to 13 (6 days) nor to series C from July 15 to 22 (8 days)

and at Mandan, N. Dak., are comparable because the climatic conditions at the two stations are very similar. The average seasonal evaporation (April to August, inclusive) was 36.54 inches during the 17-year period 1908–1924 at Newell, and 34.21 inches during the 11-year period 1914–1924 at Mandan. The average seasonal precipitation was 9.07 inches at Newell and 10.13 inches at Mandan.

TABLE 32.—*Water requirement, based on dry matter, of field crops grown at Newell, S. Dak., and Mandan, N. Dak., 1912–1922, and evaporation from June to August, inclusive, expressed as actual values and as index numbers of the mean value for each crop, taken as 100; and ratio of water-requirement index to evaporation index*

SEASONAL WATER REQUIREMENT

Data	Newell, S. Dak.							Mandan, N. Dak.				Average
	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	
Actual values:												
Alfalfa, all varieties [a]	701±7	759±6	1,036±14	602±5	694±5	898±5	947±10	706±8	670	936±33	742±11	802±10
Wheat, Kubanka, C. I. 1440	463±6	436±4	528±5	333±2	352±7	487±6	415±8	520±11	340±4	531±8	372±8	434±6
Millet, all varieties [b]	261±2	316±2	307±7	177±1	232±1	278±1	239±7	303±2	186±1	.....	.....	255±3
Sorgo, Dakota Amber	.....	.....	.....	210±4	239±2	275±2	284±3	273±1	229±2	.....	.....	252
Sudan grass	.....	.....	.....	272±2	314±5	344±5	333±3	347±4	274±3	.....	.....	314
Index numbers:												
Alfalfa, all varieties	87	95	129	75	87	112	118	88	83	117	93	100
Wheat, Kubanka, C. I. 1440	107	100	122	77	81	112	96	120	78	122	86	100
Millet, all varieties	102	124	120	69	91	109	94	119	73	.....	.....	100
Sorgo, Dakota Amber	.....	.....	.....	83	95	109	113	108	91	.....	.....	100
Sudan grass	.....	.....	.....	87	100	110	106	111	87	.....	.....	100
Average water requirement	99	106	124	78	91	110	105	109	82	120	90	.....
Ratio, WR/E	93	97	118	111	108	104	112	96	80	104	95	.....
Water-requirement index used	100	105	112	76	90	108	98	110	88	118	95	100

EVAPORATION, JUNE TO AUGUST

Actual value (inches)	22.75	23.42	22.42	15.07	18.10	22.79	20.16	24.49	21.91	24.74	20.31	21.47
Index number	106	109	105	70	84	106	94	114	102	115	95	100

[a] The water requirement of alfalfa is based upon the mean value of three varieties (18 pots) grown in 1912, 1913, and 1914; six varieties (36 pots) in 1915 and 1916; five varieties (30 pots) in 1917; four varieties (24 pots) in 1918; and one variety (6 pots) in 1919, 1921, and 1922. The value for 1920 was computed.

[b] The value for millet is based upon four varieties (24 pots) grown in 1912; three varieties (18 pots) in 1913, 1915, 1916, and 1917; two varieties (12 pots) in 1914; and one variety (6 pots) in 1918, 1919, and 1920.

The use of index numbers was suggested by Shantz and Piemeisel (*11*) in order to facilitate the comparison of the water requirement of different plants with the evaporation from year to year. The annual index number is expressed as a percentage of the mean value taken as 100.

In the present paper the writer has used the evaporation for the 3-month period June to August, inclusive, as a basis of comparison with the water requirement, while Shantz used the 6-month period April to September, inclusive, in the report of his work at Akron, Colo. The shorter period is used here because it corresponds more closely to the period of active plant growth, especially in the area represented by these experiments.

The actual water requirement of the several crops during the 11-year period ranged as follows:

Alfalfa from 602±5 in 1915 to 1,036±14 in 1914.
Kubanka wheat from 333±2 in 1915 to 531±8 in 1921.
Sudan grass from 272±2 in 1915 to 347±4 in 1919.
Millet from 177±1 in 1915 to 316±2 in 1913.
Sorgo from 210±4 in 1915 to 284±3 in 1918.

The lowest value for each crop represented was obtained during the cool, wet season of 1915. In that year the remarkably low values of 177 for millet, 333 for wheat, and 602 for alfalfa were obtained. The highest value for each crop was obtained in different years.

The effect of seasonal conditions on water requirement can be seen readily by comparison of the index numbers, which, as already noted, are based on the mean value of each crop, with the evaporation taken as 100.

The evaporation index number varied from 70 in 1915 to 115 in 1921, a range of 45 points, while the average water-requirement index number varied from 78 in 1915 to 124 in 1914, a range of 46 points. It is evident, therefore, that the climatic factors which influence and determine the quantity of evaporation from a free water surface also determine the rate of transpiration from crop plants.

Considering only the 6-year period 1915 to 1920, when all of the five crops were grown, the evaporation index varied from 70 in 1915 to 114 in 1919, a range of 44 points; the water-requirement index of the several plants varied as follows: Alfalfa from 75 to 118, 43 points; wheat from 77 to 120, 43 points; millet from 69 to 119, 50 points; sorgo from 83 to 113, 30 points; and Sudan grass from 87 to 111, 24 points. The water-requirement range of alfalfa and of wheat was almost exactly the same as the range of evaporation, that of millet was somewhat greater, while the range of sorgo and of Sudan grass was only a little over half the range of evaporation. In other words, alfalfa, wheat, and millet are highly responsive to seasonal climatic conditions, while sorgo and Sudan grass are less responsive. The effect of seasonal conditions on evaporation and on the water requirement of the five crops mentioned above is shown graphically in Figure 10.

SEASONAL MARCH OF TRANSPIRATION

It is well known in the practice of irrigation that field crops use comparatively little water during the early stages of growth, when the plants are small, and that the rate of water use increases rapidly

as the plants approach their maximum development. It is of interest to compare the transpiration of crop plants grown in the water-requirement experiments with evaporation during short periods throughout the growing season. In Figure 11 the transpiration of Kubanka wheat is shown graphically as the mean daily loss in depth of water, based on the soil-surface area of the pots, in comparison with evaporation from a free water surface, that is, from a tank 8 feet in diameter set at the ground level. The graph is based on data obtained in 1915, a cool, wet season, and in 1917, a hot, dry season, at Newell, S. Dak.

In 1915 evaporation by 5-day periods ranged from 0.08 to 0.23 inch daily from June 10 to August 31. During this time the loss of water by transpiration from the six pots of wheat increased from 0.02 inch, for the period June 10 to 15, to a maximum of 0.27 inch daily, during the period July 25 to 31. This maximum was reached after heading. A progressive decrease then occurred until transpiration amounted to only 0.10 inch during the 5-day period before harvest on August 25.

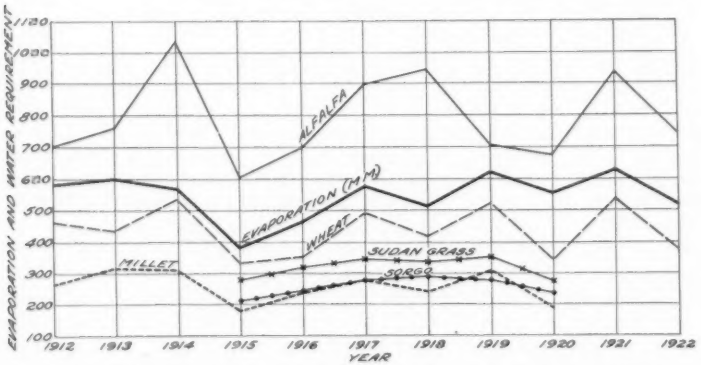

FIGURE 10.—Evaporation (June to August, inclusive) in millimeters and water requirement of alfalfa, wheat, millet, sorgo, and Sudan grass during the 11-year period 1912–1922

In 1917 both evaporation and transpiration were much higher than in 1915. (Fig. 11.) During July, evaporation exceeded 0.25 inch daily and reached 0.35 inch during one period, July 6 to 10. The daily loss of water by transpiration from wheat increased quite uniformly from the first period recorded, June 15 to 20, to the period after heading, July 21 to 25, when it amounted to 0.45 inch daily. After this period of rapid transpiration there was a progressive decrease in the rate of water use to the time of ripening. Transpiration during the last eight days before ripening averaged 0.12 inch per day as compared with 0.21 inch of evaporation.

The mean yield of total dry matter per pot was 129.6 gm. in 1915 and 113.6 gm. in 1917. It is evident, therefore, that the increase in rate of transpiration per pot in 1917 over that in 1915 was due to climatic factors rather than to a difference in leaf area, since the plants were somewhat smaller in 1917 than in 1915.

In Figure 12 the transpiration of Kubanka wheat at Mandan, N. Dak., in 1921 and 1922 is shown graphically in comparison with the mean daily evaporation by 5-day periods during the growing season.

The season of 1921 at Mandan was extremely hot and dry for that locality, and field crops were nearly a total failure. Maximum temperatures of 100° F. or higher occurred on several days in June and July, and 110° was recorded on July 9. The hot season resulted in the early ripening and comparatively low yield of wheat in the water-requirement experiments, the average dry weight per pot being 113.2 gm. in 1921 as compared with 214.6 gm. in 1922.

The daily transpiration of wheat exceeded evaporation of water from the tank during the period from June 20 to July 20, 1921, and from June 20 to August 10, 1922, both evaporation and transpiration being calculated on an equal water-surface or soil-surface area.

A growing crop is in fact a very efficient pumping system. In regions of limited rainfall, as on the Great Plains, a growing crop generally uses all the available water stored in the soil in addition to

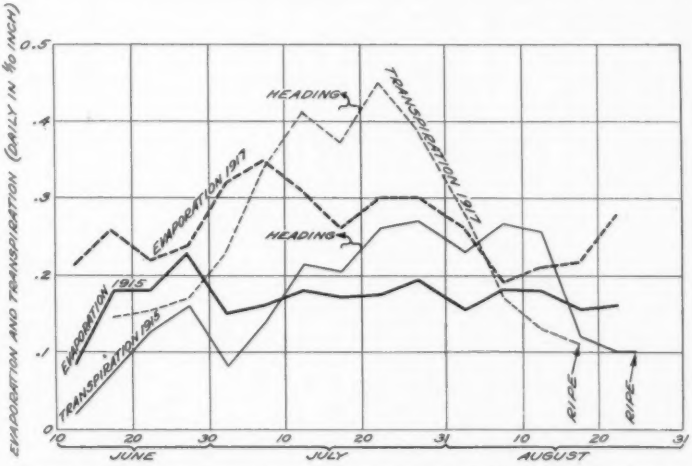

FIGURE 11.—Mean daily evaporation and mean daily transpiration of Kubanka wheat by 5-day periods at Newell, S. Dak., in 1915 and 1917. Transpiration is computed as depth of water transpired, based on the soil-surface area of the six pots of each crop grown. The progressive increase in the rate of transpiration of wheat as the plants approach the stage of greatest leaf development, usually some time after heading, followed by a progressive decrease in rate of transpiration up to ripening, is apparent

that which falls during the growing season. According to Cole and Mathews (*5*), a crop of wheat on the northern Great Plains requires at least 4 inches of water under field conditions to mature any grain at all, and it will use as much as 16 to 18 inches if it is available. When the acre yield of wheat exceeded 10 bushels, it generally required from 640 to 1,150 pounds of water to produce 1 pound of dry matter. With lower yields the ratio of water used was generally much higher.

The possibility that a crop such as wheat, during its period of rapid growth, may pump more water into the atmosphere than is evaporated from a water surface of equal area has some interesting applications. In some of the drier States the impounding of water from artesian wells and from melting snow has been suggested as a means of increasing evaporation and, supposedly, the summer rainfall. It is probable, however, that the soil itself is the most practicable storage reservoir

and the growing crop the most efficient pump to set the water free. In wet seasons, when the growth of native vegetation and of cultivated crops is luxuriant, to what extent does transpiration of vegetation contribute to the supply of atmospheric moisture which may be precipitated as more or less local showers? When soil moisture is readily available, it is possible that the transpiration of native vegetation during the early summer may equal evaporation of water from an equal area. Under irrigation it is certain that most crops in full leaf transpire more water than would be evaporated from an equal area of water surface.

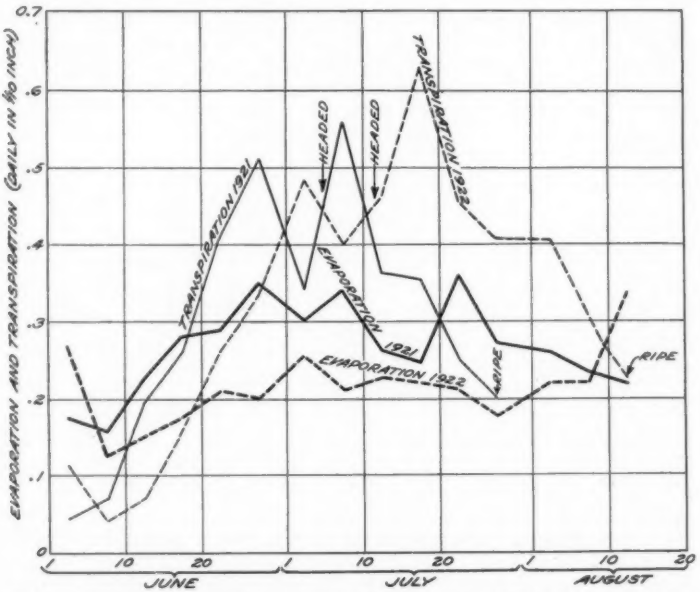

FIGURE 12.—Mean daily evaporation and mean daily transpiration of Kubanka wheat by 5-day periods at Mandan, N. Dak., in 1921 and 1922. The higher rate of transpiration in 1922 is due to the larger plants, the final dry weight of plants per pot in 1922 being 214.6 gm. as compared with 113.2 gm. in 1921. Transpiration exceeded 0.6 inch per day at the maximum (July 16–20, 1922) when, during the same period, evaporation from the tank did not exceed 0.23 inch per day

RELATION OF SEASONAL CLIMATIC CONDITIONS TO YIELD AND WATER REQUIREMENT OF WHEAT

It is of interest to observe the relation between seasonal climatic conditions, as measured by evaporation, and the yield and water requirement of wheat. Figure 13 shows graphically the yield of Kubanka durum wheat after summer fallow, the seasonal (April to July) precipitation, the reciprocal of the index of evaporation, and the reciprocal of the water requirement of wheat at Newell, S. Dak. (1912 to 1918), and at Mandan, N. Dak. (1919 to 1922). In 1915, 1916, 1918, and 1922 the yield of wheat was at or above the mean (18.6 bushels per acre) when evaporation and water requirement were well below the mean (the reciprocal is shown for more ready compari-

son). The years 1914, 1917, 1919, and 1921 were seasons of high evaporation and of high water requirement and low yields. In 1912 the crop failure was due to extreme drought during June. In 1920 drought prevailed during June and the greater part of July, and in 1921 the low yield was due to high temperatures and drought in May and June.

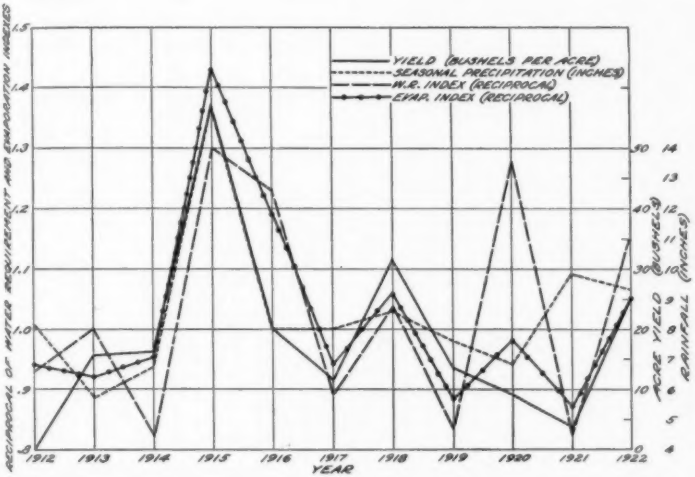

FIGURE 13.—Relation between climatic factors of evaporation and seasonal rainfall to yield and water requirement of Kubanka wheat. The yield is based on the average annual yield of five 1/10-acre plots at Newell (1912 to 1918) and of 12 plots at Mandan (1919 to 1922). All plots were fallow and clean cultivated the year previous to cropping. The seasonal precipitation is for the four months, April to July. Evaporation is for the three months, June to August, for better comparison with the water-requirement determinations, in which the wheat generally was later than in the field plots. Evaporation and water requirement are expressed as the reciprocal of the index number. (Table 32.) In 1915, 1918, and 1922 rainfall was above normal and evaporation was below normal, resulting in a high efficiency of transpiration (low water requirement), whereas in 1914, 1917, 1919, and 1921 climatic conditions were unfavorable, resulting in low yields and a high water requirement. The low yield of 1920 was due to drought in June and the greater part of July

SUMMARY AND CONCLUSIONS

A summary of the comparable water-requirement determinations made during the 11-year period covered by the experiments is presented in Table 33. The work was conducted at Newell, S. Dak., for seven seasons, 1912 to 1918, and at Mandan, N. Dak., for four seasons, 1919 to 1922. A total of 110 sets of plants, or about 660 individual pots, was grown during the investigations.

TABLE 33.—*Annual and mean water requirement and efficiency of transpiration of plants grown at Newell, S. Dak., during seven years, 1912–1918, and at Mandan, N. Dak., during four years, 1919–1922*

Plant	Annual water requirement											Years grown	Mean water requirement		Efficiency of transpiration [b]
	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922		Actual	Weighted [a]	
Wheat:															
Durum (Triticum durum)—															
Kubanka, C. I. 1440	463±6	436±4	528±5	333±2	352±7	487±6	415±8	520±11	340±4	531±8	[c] 342±6	11	432	430	2.33
Common (T. vulgare)—															
Marquis, C. I. 3641											355±7	1	355	403	2.48
Kota, C. I. 5878											393±6	1	393	447	2.24
Hard Federation, C. I. 4733											405±4	1	405	460	2.17
Oats (Avena sativa):															
Swedish Select							427±9	709±8				2	568	536	1.87
Millet (Chaetochloa italica):															
Kursk, A. D. I. 3	239±3	293±3	311±11	171±1	233±1	278±2	239±7	303±2	186±1			9	250	251	3.98
Kursk, A. D. I. 13–3	246±3	329±3										2	288	280	3.57
Siberian, A. D. I. 4–3	244±4	326±2	303±7	177±2	231±3	275±2						6	259	259	3.86
Gold Mine (Common)				182±2	231±1	280±1						3	231	253	3.95
Average	243	316	307	177	232	278	239	303	186			9	253	254	3.94
Sorgo (Sorghum vulgare):															
Dakota Amber				210±4	239±2	275±2	284±3	273±1	229±2			6	252	268	3.73
Red Amber				204±1	232±3	246±1						3	227	253	3.95
Sudan grass (Sorghum vulgare var. sudanense)				272±2	314±5	344±5	333±3	347±4	274±3			6	314	335	2.99
Bromegrass (Bromus inermis)		852±2			708±13	921±33	684±14					4	791	784	1.28
Crested wheatgrass (Agropyron cristatum)		880±10	1,024±34									2	952	853	1.18
Western wheatgrass (A. smithii)		1,247±31	1,420									2	1,334	1,183	.84
Weeds:															
Witch grass (Panicum capillare)								283±16			221±3	2	252	254	3.94
Russian thistle (Salsola tenuifolia)								237±7			204±3	2	221	224	4.46
Redroot pigweed (Amaranthus retroflexus)								272±12			242	2	257	261	3.83
Purslane (Portulaca oleracea)								317±8				1	317	288	3.47
Lamb's-quarters (Chenopodium album)											383	1	383	435	2.30
Sugar beet (Beta vulgaris)							304±6					1	304	304	3.29
Flax (Linum usitatissimum):															
Damont, C. I. 3										820±19	877±11	2	848	[d] 707	1.41
Reserve, C. I. 19										818±12	854±16	2	836	[d] 697	1.43
Primost, C. I. 12										748±4	801±8	2	774	[d] 645	1.55
N. D. R. 114, C. I. 13										756±6	729±17	2	742	[d] 618	1.62
Winona, C. I. 179											738±9	1	738	[d] 615	1.63
Letheridge Golden, C. I. 23											902±5	1	902	[d] 752	1.33
Average										786	817		802	[d] 668	1.50
Yellow-flowered alfalfa (Medicago falcata)	662±12	579±12	[b] 1,094±20	541±9				731±13				5	721	702	1.42

Alfalfa (Medicago Sativa):															
Turkestan, A. D. I. F–12–30				1,210±16	695±12	659±9	896±9	937±23				5	879	887	1.13
Grimm, A. D. I. F–23		735±15	735±8	1,038±25	696±18	673±8	866±16	955±10	706±8		936±33	9	816	795	1.26
Grimm, A. D. I. F–5–30				1,005±24	601±6	718±11	908±16	1,023±24				5	831	833	1.20
Baltic, A. D. I. H–4–58				1,066±25	554±10	700±13	881±9	871±15				6	802	823	1.22
Grimm, A. D. I. 81					667±7	713±20	939±17				742±11	3	773	850	1.18
Average		735	735	1,080	623	693	898	946	706		936	10	809	798	1.25
Evaporation index		106	109	105	70	84	106	94	114	102	115	95	100		
Mean water-requirement index		99	110	124	78	91	110	105	109	82	120	88			
Water-requirement index used		100	105	120	75	90	108	100	110	84	120	88	100		

[a] Based on the "water requirement index used" as correction for seasonal variation.

[b] The term "efficiency of transpiration" is used by Maksimov (*7, 8*) to express the number of grams of dry matter produced for each kilogram of water transpired. It is the reciprocal of water requirement × 1,000.

[c] Mean of two sets, 12 pots.

[d] Based on index of 120 for both 1921 and 1922.

As many of the crops were grown for only a part of the period, some correction must be made for the character of the growing season if the mean values of different crops are to be compared. This has been done in the column headed "Weighted mean" which is based on the "water-requirement index used" as shown in the last line of Table 32. For example, the weighted mean value of Kubanka wheat is the mean of the annual values each divided by the "water-requirement index" of that year. The actual mean value for Kubanka wheat was 432 and the weighted mean was 430. On the basis of the weighted mean it is possible to compare the water-requirement values of the different crop plants and weeds represented. The lowest values, based on dry matter, were found in the millets and sorgos and the highest values in the alfalfas and grasses. In the last column is shown the "efficiency of transpiration," a term used by Maksimov (7) to express the number of grams of dry matter produced from 1,000 gm. of water transpired.

The range of water requirement is very wide, extending from 224 for Russian thistle to 1,183 for western wheatgrass. The lowest actual value obtained from any crop was 171 ± 1 for Kursk millet, A. D. I. 3, in 1915.

As mentioned above, Kubanka wheat had a weighted mean water requirement of 430, or an efficiency of transpiration of 2.33. Three varieties of common wheat each had a somewhat higher water requirement than Kubanka durum wheat in 1922, the only year they were grown. Swedish Select oat, grown only two seasons, had a weighted mean value of 536 or a transpiration efficiency of 1.87.

Kursk millet, A. D. I. 3, grown for nine seasons, had a weighted mean water-requirement value of 251. This value was considerably lower than that of Kursk, A. D. I. 13–3, a sib selection (280), but about the same as that of the Siberian (259) and Gold Mine (253) varieties. Apparently Red Amber sorgo (253) was slightly more efficient in the use of water than Dakota Amber sorgo (268), though this difference may have been due to maturity, Dakota Amber usually maturing a normal yield of seed, while Red Amber did not except for a small yield in 1916. Sudan grass is much less efficient in the use of water than millet or sorgo. Its water requirement was 335, or about 25 per cent higher than that of Dakota Amber sorgo.

The perennial grasses—bromegrass, crested wheatgrass, and western wheatgrass—gave weighted mean values of 784, 853, and 1,183, respectively. These values are probably too high as compared with the real efficiency of the grasses as dry-land crops. All are perennials, and during late summer under normal conditions they store organic food material in their rhizomes and roots, which enables them to produce an early summer crop the following year with probably an efficient use of water. (See Table 17.)

The annual weeds—witch grass, Russian thistle, redroot pigweed, and purslane—had low weighted mean values, ranging from 224 for Russian thistle to 288 for purslane, as compared with 435 for lamb's-quarters. The Russian thistle is remarkably efficient in the use of water, and this probably explains why it is such a serious weed pest in dry seasons. Sugar beet grown only one season had a water requirement of 304, based on total dry matter of roots and tops.

The actual mean water requirement of six varieties of flax ranged from 738 to 902. The values obtained in 1922 were abnormally

high, in spite of the favorable growing season, due to the fact that (in the writer's absence) the soil was kept too moist during the ripening period, thus stimulating late vegetative growth after the seed bolls were mature. This effect was not so evident in the early variety, N. D. R. 114, which had a lower value in 1922 than in 1921. The average weighted-mean value of 668 for all varieties probably is near the true value under normal conditions at Mandan.

Yellow-flowered alfalfa (*Medicago falcata*) had a weighted mean water requirement of 702, as compared with 798 as the average weighted mean value of varieties of *M. sativa*. *M. falcata* shows a remarkable difference in the water requirement of successive crops. In 1913 (Table 16) the first crop, harvested June 30, had a water requirement of 340 ± 7; the second crop, harvested August 6, had a value of 713 ± 11; and the third crop, harvested September 18, had a value of $1,220 \pm 52$. These pots were planted in 1912. Very similar results were obtained with Grimm alfalfa when the plants were overwintered. In 1913 (Table 13) the three crops of Grimm, A. D. I. E–23, harvested on the same dates as *M. falcata*, gave a water-requirement value for the early-summer crop of 469 ± 6; for the midsummer crop, 817 ± 13; and for the late-summer crop, $1,115 \pm 16$. Alfalfa is in fact quite a dependable crop in dry-land farming on the northern Great Plains, although in most seasons it produces only a single early-summer crop. This one crop, as shown above, probably is produced with a water requirement only a little higher than that of wheat.

The results of the experiments, although not conclusive, throw some light on the problems suggested in the introduction, namely:

(1) Whether the water requirement can be used as a measure of the relative adaptation to conditions of drought of different varieties of the same crop. The data available indicate that there are small but significant differences in the water requirement of different varieties of the same crop. However, as the water-requirement value in pot experiments as usually conducted is determined under conditions of adequate soil-moisture supply, it probably is not a dependable measure of the adaptation of a variety to conditions of drought. A low water requirement suggests adaptation to drought, but the final measure of the value of a variety must be the actual yield as determined by carefully conducted field-plot tests.

(2) Whether similar varieties or selected progeny strains show appreciable differences in water requirement. The water requirement of related strains of millet and of alfalfa did not show significant differences over a period of years. (Table 33.) As pot experiments are subject to errors of experimentation, especially in any factors which affect the yield of the plants, it is doubtful whether the water requirement can be used as a precise measure of the value of related strains. In nearly all experiments with millets the probable error based on six pots of each variety was very low; whereas, with alfalfa, the probable error was comparatively high. Although the methods of experimentation in water-requirement determinations may not be refined enough to measure small differences between selected strains of a variety, or between similar varieties, they do indicate the great range of values of different crop plants. It is this knowledge of the water requirement of different crop plants and weeds which is of significant practical importance.

(3) Whether the water requirement of crop plants is correlated with yields as determined by plot tests in the field. In the case of Kubanka wheat there was in most years a significant relation between the water requirement and the yield of grain in the field. This subject is discussed under the topic "Relation of Seasonal Climatic Conditions to Yield and Water Requirement of Wheat."

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THE TOXICITY OF CORYDALIS CASEANA[1]

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INTRODUCTION

Serious losses of sheep on certain portions of summer range in the Plumas National Forest, Calif., directed suspicion to a succulent plant growing in some of the canyons of the range. The owner of the flocks submitted samples of the suspected plant, which was identified as *Corydalis caseana* Gray. This identification was later confirmed through the courtesy of the Forest Service of the United States Department of Agriculture. The plant is also referred to as *Capnoides caseana*. Because of the effect of the plant on sheep the name "fit weed" has been suggested for common use.

Fresh material collected in July, 1929, was used in feeding experiments with sheep at this station. These tests demonstrated conclusively that the plant is toxic. The results of these tests will be presented as a publication of this station from the department of range management. Material collected in 1929 and 1930 was used in the work with rats herein reported.

BOTANICAL DESCRIPTION OF CORYDALIS CASEANA

Corydalis caseana Gray belongs to the order Fumariaceae and is described (*8, p. 96, 467*)[3] as follows:

Caseána, GRAY. Stem rather lax and succulent: hood of the outer petals concave, with spreading margins, pointless or short-pointed, and bearing a rather broad and apically projecting dorsal crest: mature fruit unknown, the forming capsules barely half inch long, elliptical, obtuse.—Proc. Am. Acad. X. 69; Wats. Bot. Calif. ii, 429. *C. Bidwelliæ*, Wats. l. c.—In water or on very wet banks, Sierra Nevada, California, from Truckee River to the Big Spring district in Plumas Co., *Bolander, E. L. Case, Lemmon, Mrs. Austin, Mrs. Bidwell, Parry.*

C. Caseana Gray, p. 96. Add syn. Capnoides Caseanum, & *C. Bidwellianum*, Greene, l. c. 280.

PREPARATION OF THE CRUDE ALKALOIDAL MATERIAL

So far as the available literature discloses, no chemical investigation of *Corydalis caseana* has been reported. However, notable researches on the alkaloids of the bulbous roots of *C. cava* have been made by Freund and Josephy (*7*), Dobbie and Lauder (*1, 2, 3, 4, 5, 6*), and others. The aboveground portions of *C. cava* have been but little studied, although Haars (*9*) reports finding bulbocapnine in the tops, and also two other alkaloids. He did not, however, find corydaline in the tops, a constituent which is present in greatest quantity in the roots. Protopine, which has been reported as occurring in the roots, he found to be lacking in the aboveground parts.

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[2] Grateful acknowledgment is made of the assistance in parts of this work given by Dr. Lyman R. Vawter, of the veterinary department of this station.

[3] Reference is made by number (italic) to Literature cited, p. 243.

A portion of the fresh green plants collected in July, 1929, was received at the laboratory in good condition. A sample, when dried at ordinary room temperature lost 92.7 per cent of its weight; the material collected in July, 1930, lost 91.8 per cent. These figures indicate the succulence of the plant.

Preliminary work on the fresh green plant was undertaken to determine the presence of alkaloids. For this purpose, the green plant tissues were broken up and allowed to stand 24 hours with an equal volume of 95 per cent alcohol. The alcoholic extract was removed by pressure, concentrated to a sirup, mixed with purified sawdust and dried. Successive extractions were made on the sawdust mixture, using petroleum ether, benzol, and chloroform. Each of these solvents yielded material that gave positive reactions with the general alkaloidal reagents, after their removal with dilute sulphuric acid and recovery by extraction with ether. The alkaloidal reagents used were Dragendorff's, Mayer's, and Wagner's, and silicotungstic acid.

The plant residue, after removal of the alcoholic extract and washing, was air-dried, ground, and extracted with a dilute aqueous solution of tartaric acid until the liquid from the percolator was colorless. The extract was then concentrated to approximately one-fifth its volume, the precipitated material removed, and the clear liquid extracted with ether. The material removed by the ether gave no indication of the presence of alkaloids with the alkaloidal reagents. The acid aqueous extract was then made distinctly alkaline with sodium hydroxide and again extracted with ether. After removal of the ether a small residue remained, which gave positive reactions with the alkaloidal reagents.

A small portion of air-dried and ground plant was extracted in the cold with 95 per cent alcohol, the extract concentrated to a thick sirup, and treated with dilute acetic acid. The yellowish-brown aqueous solution so obtained, made alkaline with ammonium hydroxide and extracted with ether, yielded, after drying, a sirupy residue amounting to 0.85 per cent of the dry plant used. After this residue had stood for several days a very small amount of crystalline material separated. The crystals and mother liquor were taken up with dilute hydrochloric acid and after having been made alkaline were again extracted with ether. The solid material obtained from the ethereal solution was again treated in the same manner and finally yielded a very small quantity of crystals in spherical masses, which, when further purified by recrystallization from ethyl acetate, melted at 199° C.

Determinations of the content of crude alkaloids were made on the air-dried plant by the ordinary method. Ten-gram samples were macerated with Prollius's fluid for 24 hours, the extracts removed by suction, and the residues washed with alcohol. The filtrates were shaken out with several portions of dilute sulphuric acid, the acid aqueous extracts made slightly alkaline with sodium carbonate, and extracted with ether in several portions. The ethereal extracts were colored yellow. After washing and drying, the solvent was removed, and the residues were dried over sulphuric acid and weighed.

The assays showed that the air-dried plant which had been collected in 1929 contained 1.10 per cent of crude alkaloids, and that collected in 1930, 1.90 per cent. The crude alkaloidal residue, when dry, con-

sisted partly of a nearly white granular material and partly of a yellowish-brown, varnishlike mass. When treated with dilute hydrochloric acid and warmed, the residues were nearly completely soluble, giving yellowish-brown solutions and leaving small quantities of dark-gray resinous matter. The solutions so formed gave positive reactions with the alkaloidal reagents.

PHYSIOLOGICAL TESTS

An effort was next made to determine the toxicity of the crude alkaloidal residues from the material gathered in 1930. They were first dissolved in a small quantity of very dilute hydrochloric acid and the solutions made to volumes of 10 c. c. A rat weighing 200 gm. was then injected subcutaneously with 0.50 c. c. of one of these solutions. After 10 minutes the animal became markedly depressed and moved about very slowly when not remaining quiet. It continued in this condition for approximately 3 hours but gradually became as active as before the injection. Observation for several days gave no indication of further symptoms. Another 200-gm. rat injected subcutaneously with 0.25 c. c. of the same solution showed the same quieting effect in about 10 minutes. Unlike the first animal, this rat began to exhibit clonic convulsions after 15 minutes, and these increased in severity until it died 45 minutes after the injection. Post-mortem examination showed dilation of the heart and congestion of the lungs. Moderate congestion of the upper part of the small intestine was also observed, with traces of blood in the intestinal contents. The heart had stopped in systole. A striking cyanosis of the mucous membrane of the mouth was noted. Death had resulted apparently from respiratory failure. Why the smaller dose should have been more toxic than the larger is not clearly understood.

A duplicate preparation, similar in all respects to the one used above, except that it had been allowed to stand for 24 hours, was next used. Two 200-gm. rats were each injected subcutaneously with 0.25 c. c. of this solution. Both showed the sedative effect in 15 minutes, remained quiet for approximately 3 hours, and recovered. Two 200-gm. rats were similarly injected with 0.50 c. c. of the preparation. In 15 minutes both became quiet. After 30 minutes one had intermittent mild convulsive seizures for a period of approximately an hour, after which it gradually became more normal, and after 3 hours both were more active and finally recovered. A 200-gm. rat was injected with 0.25 c. c. of the same solution as that used in the first test, 24 hours after its preparation. In 20 minutes the rat became quiet, remained in this condition for nearly 3 hours, and then made a rapid recovery.

The result here noted, namely, the greater action of the more recently prepared solution, called to mind the work reported by Dobbie and Lauder (*1*). These investigators state that corydaline, obtained from crude corydaline as supplied to them by Schuchardt and prepared from the roots of *Corydalis tuberosa*, is sensitive to light and heat. According to their observations, light and heat produce a change in corydaline, resulting in a yellow alteration product which is without the properties of the original substance.[3]

[3] A similar alteration in nicotine solutions after exposure to the mercury vapor lamp has been reported by A. J. Pacini and McGuigan. (*10*).

With this in mind the writer made new preparations, using the same quantity of dry plant (10 gm.) and the same method. All of the work, however, was carried out in subdued daylight, sufficient only for convenience in manipulation. The solutions in very dilute hydrochloric acid were prepared by warming, as before, except that they were exposed to the heat of the water bath for a shorter period than formerly. The volume of the solutions was 10 c. c. as above. After preparation, the solutions were kept in a light-proof container until used. The solutions were administered as soon as possible after preparation.

A freshly prepared solution of crude alkaloidal residue which had been separated in subdued light was injected subcutaneously in increasing doses into rats weighing 200 gm. Administration of 0.25 c. c. produced a sedative effect only; 0.35 c. c. produced a quieting effect followed by intermittent spasms, with recovery; 0.40 c. c. and 0.50 c. c. produced quieting, then convulsions, and 30 minutes after injection, death. Autopsy of the rats killed in this series of tests showed changes similar to those described above.

In all the work the same concentrations were used. The very dilute hydrochloric acid solution was equivalent, per cubic centimeter, to 1.0 gm. of air-dry plant, 12.2 gm. of fresh plant, and 0.0190 gm. of crude alkaloids.

Based on the results obtained by using alkaloidal material prepared in subdued light, the lethal dose for 200-gm. rats (0.40 c. c.) is equivalent to 0.0076 gm. of crude alkaloids, or 4.88 gm. of fresh plant. This is equivalent to 24.4 gm. of fresh plant per kilogram of body weight.

CONCLUSIONS

That *Corydalis caseana* is highly toxic is shown by the results given above. From the results reported in the literature, plants belonging to this family appear to be rich in alkaloids. It is presumed that in *C. caseana* there exists more than a single alkaloid, and this point is being further studied at this station.

SUMMARY

Serious losses of sheep on certain portions of summer range in the Plumas National Forest, Calif., directed attention to a plant identified as *Corydalis caseana* as the possible cause of death. Chemical examination of the plant resulted in the preparation of from 1.10 to 1.90 per cent (on a dry basis) of crude alkaloidal material therefrom. Physiological tests demonstrated the toxicity of the plant. The lethal dose for 200 gm. rats was equivalent to 0.0076 gm. of the crude alkaloids, or 24.4 gm. of fresh plant per kilogram of body weight.

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AN ANALYSIS OF REPUTED PATHOGENICITY OF THYSANOSOMA ACTINIOIDES IN ADULT SHEEP[1]

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INTRODUCTION

Since the work of Curtice (*1*)[3] there have been numerous reports concerning the pathogenicity of the fringed or fimbriated tapeworm, *Thysanosoma actinioides* (*Taenia fimbriata*) Dies., 1834. Ofttimes these reports, especially more recent ones, are contradictory regarding symptoms and diagnosis. "Fimbriata" infection, like hemorrhagic septicemia, is all too often a convenient blanket term to cover various ailments of sheep.

Very often loco and silvery lupine poisoning have been confused with the tapeworm infections. Curtice (*1*) considered the condition of many so-called locoed sheep due to this parasite. Ward (*8, p. 288*) states: "It seems probable that the loco of the western sheep has for its exciting cause this or a similar form." Marshall (*5*), on the other hand, examined 11 locoed sheep and found 9 of them harboring the fringed tapeworm. Durrell and Glover (*2*) found chronic lupine poisoning more common in sheep than loco, the latter being more prevalent in horses. They found that lupine poisoning is often associated with liver disorder and jaundice. It is not the purpose of this paper to consider the relationship of tapeworm infection to poisoning but to point out that, contrary to popular belief, Thysanosoma infection is rarely lethal to adult sheep.

Attention was directed to the problem by the fact that recently in certain feed lots in Minnesota excessively high mortality occurred, mounting to weekly losses of 14 sheep per thousand. Post-mortems by veterinarians revealed *Thysanosoma actinioides* in the liver and bile passages. The losses were attributed to this parasite, although the symptoms were atypical. The explanation was that the presence of the tapeworms in the bile and pancreatic ducts prevented the flow of these juices into the small intestine. Since these essential juices were lacking the flow of food from the stomach was immediately closed off. The stomach would thus be full of food in a fermenting condition, and the animal would die of autointoxication. A copper sulphate treatment was advised. This supposedly caused many of the sheep to recover and presumably removed the worms from the intestine and the liver with equal efficacy. This was regarded as substantiated by port-mortems on three sheep, all of which were found negative.

This theory of the rôle of thysanosoma being accepted, the writer was asked to take up the study of the life cycle of the worm with a

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[3] Reference is made by number (italic) to Literature Cited, p. 249.

view to developing control measures. Early in the work doubt arose as to the validity of the previous conclusions and it was decided to study the incidence of the thysanosomes in sheep presenting symptoms of succumbing to the disorder.

RESULTS OF EXPERIMENTAL EXAMINATION OF SHEEP

Doubts first arose in connection with the records of mortality among some 30,000 sheep over a 2-year period. As shown in the curve, the greatest losses occurred toward the end of the feeding period. (Fig. 1.) Figure 2 shows the normal death rate of sheep under feed-lot conditions. Providing chances for reinfection are not present, one would expect the peak of the curve near the beginning of the feeding period when the most heavily diseased animals would die. Again, one would expect the highest mortality when the weather conditions were adverse as pointed out by Curtice (*1*) and Ward (*8*). Upon this basis the losses were charted against the temperature. During the subzero weather of January the mortality curve approached the base line, and during the abnormal moderate weather of December the peak in the curve was reached.

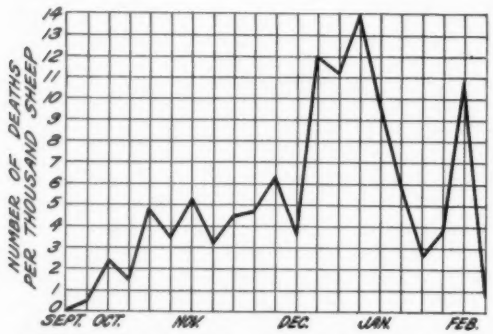

FIGURE 1.—Excessive mortality of sheep beginning two and one-half months after the animals were placed on feed; the peak occurred during moderate winter weather, the low points during colder weather

In a preliminary examination to determine the extent to which the fringed tapeworm might be incriminated, 12 sick sheep, which presented typical symptoms of the prevailing disorder, were selected from the isolation pen. Some were on the verge of collapse. All had diarrhea, a certain nervousness expressed by shaking of the head, but were possessed of good quality in wool and flesh. Postmortems showed that four were infected with the tapeworm, but that only one had sufficient numbers to clog the bile ducts materially. Yet all presented typical symptoms, and some were down prior to the time the examination was made. None showed evidence of jaundice.

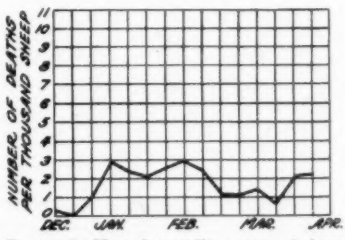

FIGURE 2.—Normal mortality curves of sheep under feed-lot conditions for comparison with Figure 1; here also fluctuations correlate closely with temperature values

The next 250 sheep showing typical symptoms, many on the verge of collapse, were killed and examined. The result was astonishing. Here the rate of infection by *Thysanosoma actinioides* was but 4.1 per cent. This slight incidence in the same lot of sheep examined

by the veterinarian could readily account, upon a chance basis, for the three uninfected animals treated with the copper sulphate, as previously mentioned. A physical examination of the 10 sheep represented by the 4.1 per cent showed little intestinal inflammation, no appreciable glandular enlargement, and the meat to be of excellent quality and the wool in perfect condition. Indeed these sheep were among the biggest and fattest in the lot, and did not at all appear as if infected by an insidious disease.

These studies led to the examination of 253 apparently normal sheep for comparison. In this lot 6.7 per cent were infected, or a 2.6 per cent higher rate than in those presumably dying from the tapeworm. This was subsequently checked by the examination of 500 more apparently normal animals, from the same pen containing the sick sheep, and a 5 per cent infection was noted, this again being higher than in the ailing sheep.

In making the examinations only the liver and the bile ducts were examined. This was done on the assumption that it is in these localities that the lethal action occurs. To render the above statistics more valid it must be shown that there was no migration of the worms into the intestine after the death of the animal and that the liver infection is really an index to the rate of intestinal infection. This was done in the following manner:

Post-mortems were performed on 100 apparently normal sheep, they being first examined for hepatic infection, and then checked for intestinal incidence. Of these, 20 per cent showed infection, 15 per cent having parasites in the liver and intestine and 5 per cent in the liver alone. Then a similar lot of 125 apparently normal sheep was examined and a 74 per cent infection found. These sheep were shipped from Colorado, where the parasite is reported to be most common. In these the intestinal infection was checked first, with subsequent liver examination. Eight animals had hepatic infections alone, 50 had intestinal infections, and 35 had coincident infections of the liver and the intestine. It is thus clear that although the intestine is the primary habitat of this tapeworm, it also is found quite commonly in the liver. It seems that a concentrated bile content is essential for the parasite, inasmuch as it is found only in the upper part of the duodenum, the liver and bile ducts, and rarely in the pancreatic ducts.

DISCUSSION

It has been assumed that the pathogenicity of thysanosomes was produced by clogging the bile passages. In the last lot of sheep examined a few presented traces of jaundice in the conjunctivae and the subcutaneous tissues. It was decided to study the extent of bile stoppage in such animals. To demonstrate this the sheep having a slight jaundice because of extremely heavy infection were tested for bile, using both Gmelin's and Kettendofer's tests. All were positive for bile in both the duodenum and the feces.

These studies show that the fringed tapeworm did not cause the losses in the present case and that this diagnosis resulted from the chance finding of worms commonly regarded as lethal. To recall the recorded symptoms associated with this parasite we refer to Curtice and Hall.

Curtice (*1*) reports that lambs infected with thysanosomes are large-headed, with undersized bodies and hidebound skins. Their gait is stiff, and they have difficulty cropping the shorter grass. Others do not see well, and apprehend danger poorly The liver is smaller, the kidneys flabbier and paler, the lymphatics somewhat darker and the muscles thinner and weaker than in normal animals. In all cases there is leanness of muscle and a diminution of fat. The symptoms and pathogenic lesions are those of malnutrition. These conditions prevail in both adults and lambs in heavy infections.

Hall (*3*) reports that the obstruction of the bile ducts causes inflammation of these ducts. The parasite causes alteration of secretion, with digestive disorders as a consequence. An unthrifty condition is produced which shows in poor quality of flesh and wool. Infected sheep are liable to die during adverse weather conditions and are commonly hidebound and suffer from diarrhea.

On the other hand, Jungherr and Welch (*4*) find stiff gaitedness due to three infections: (1) Umbilical infection, (2) coccidiosis, and (3) *Vibrion septique* infection. Welch (*9*) reports the fringed tapeworm as common in the bile ducts of young lambs and old ewes in Montana, but is unable to attribute actual damage to it. This same attitude is taken by Newsom and Cross (*6*), who consider this tapeworm of little significance.

In the earlier part of this paper reference is made to the use of copper sulphate for removing the worms from the affected sheep. All authorities agree that medication is ineffective, removing at best only worms located in the intestine. Curtice (*1*) tried all of the standard taeniafuges with no success. Ward (*8*) discourages treatment on the basis that drugs used to kill the parasites in the liver would undoubtedly have a serious effect upon the host. Hall (*3*) states that no successful treatment is known, those used having failed, and that the best recommendations for infected animals are careful nursing and good feeding.

Stiles (*7*) in summarizing the distribution of *Thysanosoma actinioides* lists the following countries and States: Brazil, Colorado, Utah, Nebraska, New Mexico, California, Oregon, Missouri, and Washington, D. C. (imported from Colorado). Hall (*3*) finds the eastern limit to be North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas. W. A. Riley records the occurrence of *T. actinioides* in Minnesota, in addition to this range. Of 30 native Minnesota sheep examined by the writer 5 were found infected with this parasite.

SUMMARY

The symptoms associated with infection with *Thysanosoma actinioides* are often confused, and therefore it has been given undue pathogenic importance. Post-mortem studies of over 1,200 sheep here reported have shown that in well-organized feed lots no great damage is done to the host except where excessively heavy infections occur. In cases of heavy infection the symptoms simulate those of malnutrition, and this fact should be given due weight before the mortality is attributed to the presence of a few thysanosomes in the liver. The conditions prevalent in the ailing sheep examined were fairly similar to those of sheep suffering from apoplexy as described by Wing (*10, 11*), or from what Newsom and Cross term "overeating." Unlike

the work of the latter writers, however, the author's studies show but few animals to have the extensive hemorrhagic areas which they figure.

The liver appears to be part of the normal habitat of the parasite. Whether the migration to that locality is cyclic or not can not be said, but it is evident that the parasite occurs there almost as frequently as in the intestine.

Even where the liver infection is most heavy, analyses show that bile is present in both the duodenum and feces. Undoubtedly, as Curtice holds, the flow is not of normal regularity. For that matter a sheep's feeding is not periodic in feed lots, and much of the bile could function in a normal manner.

The area in which *Thysanosoma actinioides* infection occurs is gradually increasing. Minnesota sheep are infected as well as those from regions previously recorded. In spite of this gradual spread, and the prevailing idea of its pathogenicity in growing lambs, nothing is yet known regarding the life cycle of *T. actinioides* except that it probably requires an intermediate host.

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